Modeling the Washington State Energy Code - 2006 & 2018 Baseline Energy Consumption

ECOTOPE

Final Report

Prepared for:

Department of Enterprise Services

State of Washington

Authored by:

Ecotope: Henry Odum, Scott Spielman, Adria Banks, Paul Kintner, Mark Frankel

O'Brien360: David Reddy, Jireh Peng

September 18, 2020

Project Team and Authors:

Commercial energy modeling was led by O'Brien360. Ecotope completed residential modeling and provided overall project direction and data analysis.

Acknowledgements:

Thank you to Richard Brown and the Department of Enterprise Services for providing support and direction for this study. We appreciate the contributions of all stakeholders including the Department of Commerce, Washington State Building Code Council, Northwest Energy Efficiency Council (NEEA), Building Industry Association of Washington (BIAW), Members of the MVE Committee, and all public comments received during review.

Table of Contents

EXECUTIVE SUMMARY 1
INTRODUCTION 3
MODELING METHOD 4
RESIDENTIAL SECTOR 6
Residential Prototype Development 6
Weighting 7
Residential Building Modeling Inputs 8
Building Components 8
Section R406 Measures (2018 WSEC) 10
Residential Building Modeling Process 11
Residential Building Results and Analysis 12
COMMERCIAL BUILDING ENERGY MODELING 16
Commercial Building Prototype Development 17
2006 HVAC System Selection 19
2018 HVAC System Selection 19
Weighting 20
Commercial Building Modeling Inputs 21
Commercial Building Modeling Process 23
Post Processing Calculations 25
Summary 26
Commercial Building Analysis and Results 26
Code to Code Comparison 26
Comparing 2006 and 2018 WSEC Results 26
Comparing the 2006 Baseline to Measured Results 29
Phase Two Sensitivity Analysis 31
Research on building operational characteristics 31
Additional Modeling 32
Key Factors in Sensitivity Analysis 32
Range of Performance 37
Updating the Baseline 39
CONCLUSION 40
REFERENCES 43

Appendix A – Detailed residential building Inputs 44
Appendix B – Detailed Residential Modeling Results 45
Appendix C – Commercial HVAC System Types 46
Appendix D – Commercial Building Type Descriptions 50
Appendix E – Commercial Building Modeling Inputs 52
Appendix F – Market Research results 53

TABLE OF FIGURES

Figure 1. Progress of the Residential and Commercial Energy Codes Towards RCW 19.27A Targets.......... 2
Figure 2. Residential Sector EUI by Code Year (2006 and 2018) 12
Figure 3. Residential EUI By Code Year and Percent Savings by Building Type 13
Figure 4. Residential End-use EUI by Building Type and Code Year.......... 14
Figure 5. Average Modeled EUI of a Single-Family Dwelling (by EUI) in 2018 – Gas vs Electric.......... 16
Figure 6. Commercial Modeled EUI Comparison by Building Type by Code Year 27
Figure 7. State Comparison Including Regulated and Unregulated End Uses 29
Figure 8. Phase One 2006 Commercial Building Modeling Results (4C Climate) with Comparison Datasets 30
Figure 9. Impacts of Internal Gains on Heating Energy Use for the Primary School Prototype with Gas Heating.......... 33
Figure 10. Impact of change in WWR on end-use energy for 2006 Medium Office prototype (dashed line shows modeled baseline WWR value).......... 35
Figure 11. 2006 baseline model average EUI variation due to unregulated loads (4C Climate) with Comparison Datasets 38

TABLE OF TABLES

Table 1. Residential Prototype Characteristics 6
Table 2. HVAC System Types for Residential Prototypes.......... 7
Table 3. Residential Weighting by House Size 8
Table 4. Residential Weighting by Heating System Type.......... 8
Table 5. Residential Weighting by Climate Zone 8
Table 6. Single-family and Multifamily Weighting by Total Residential Floor Area.......... 8
Table 7. Summary of the Option Table (Table R406.3) from the 2018 Residential Energy Code.......... 10
Table 8. Selected Measures from Table R406.3 for Each Prototype in 2018 11
Table 9. Modeled Annual Energy Consumption of Appliance and Plug Loads by Housing Type by Year... 14
Table 10. Federal Minimum Equipment Efficiencies compared to Table R406.3.......... 15
Table 11. Statewide Commercial Weighting by Building Floor Area 20
Table 12. Summary of Significant Code Changes Between 2006 and 2018 Commercial Building Models 22
Table 13. Modeled C406 Measures by Prototype 23
Table 14. Energy Use Intensity and Percent Change by Commercial Building Type - 2006 and 2018 28
Table 15. Comparison of Phase One and Phase Two EUI Values.......... 40
Table 16. Residential Building Prototypical Characteristics.......... 44
Table 17. Residential Building Code Minimum Default Inputs by Code Year 44
Table 18. Modeled 2006 Commercial HVAC System by Prototype 46
Table 19. Modeled 2018 Commercial HVAC System by Prototype 48
Table 20. Commercial Building Prototype Descriptions Compared to CBSA Building Types.......... 50

EXECUTIVE SUMMARY

Washington State law (RCW 19.27A.160) mandates that buildings built to the 2031 energy code use 70% less net-energy when compared to 2006-era buildings. The purpose of this study was twofold: first, it sought to establish the 2006 baseline energy use for the residential and commercial sectors and to provide a starting point for measuring our progress towards the mandated reductions. Secondly, it set out to determine how far the energy code has come in contributing to those reductions. As originally conceived, this study was designed specifically to assess changes in code stringency that contribute to the overall building sector goal of a 70% energy use reduction by 2031. A second phase was added to the project to consider market characteristics of the building stock outside of code performance factors, and to consider the sensitivity of the performance results to changes in non-code building characteristics.

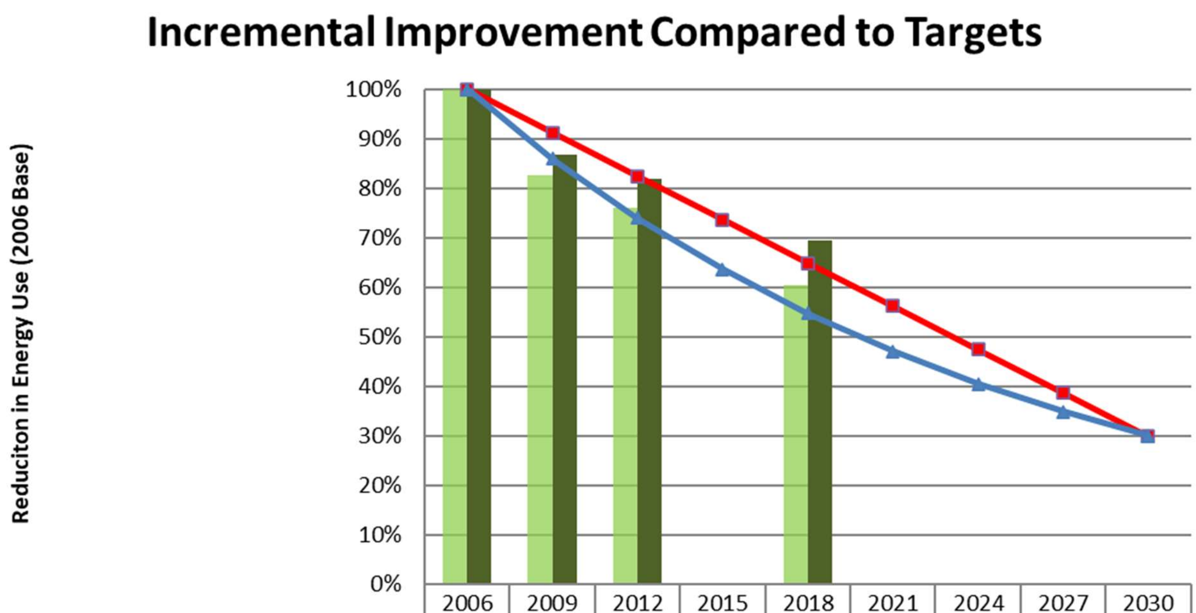
Different modeling software was used for each sector, but the approach remained the same. Residential and commercial prototypes, developed by the Regional Technical Forum (RTF), were sourced for the majority of the modeled buildings in this study, with a few specific building types (mid- and high-rise multifamily, outpatient healthcare, and a 5000sf single family home) added to capture more of the building sector. Statewide building trends were developed from regional building stock assessments and field studies to develop a saturation of common building types (by primary occupancy), HVAC systems, and location within the state (climate zone 5B or 4C). With prototypes developed and all weighting estimates developed, the project team then applied all prescriptive requirements from the 2006 and 2018 Washington State Energy Code (WSEC) to determine the expected energy consumption under each code cycle.

The first phase of this study focused on showing the measurable energy savings purely brought by the energy code (or other required documents, such as state law), using specific prototype assumptions for unregulated loads and building characteristics that align with previous analyses and RTF guidelines. One such example was heating fuel sources—this study assumed the code does not affect which fuel source is chosen by builders or design teams, therefore primary heating fuel source was kept constant between the two analysis years. Beginning with the 2018 code, however, the code has begun to account for site carbon emissions as opposed to solely site energy use. While this should be accounted for in future studies, any adjustment to commonly selected heating fuel source must be informed by building surveys to document any measurable change in building trends.

In the second phase of the analysis, research into building operating patterns and unregulated load characteristics was used to modify prototype parameters to assess the impact of different operating assumptions on predicted energy use. This sensitivity analysis demonstrated that different assumptions about non-code building characteristics contributed to some misalignment between the predicted performance of the building prototypes with measured data from field studies for similar building types. More importantly, the sensitivity analysis indicated that predicted energy end use breakdowns were substantially depended on assumptions about unregulated loads, suggesting that better data about unregulated load characteristics would support better decisions on code development priorities.

Revised performance ranges for key building types were compared to measured data from performance disclosure and research sources to assess the alignment of the predictions with actual building performance. The results of this comparison and the sensitivity analysis were used to update certain building prototype characteristics, and to update the assessment of building performance for the 2006 baseline.

Modeling results show that residential estimated energy consumption under the 2018 WSEC is approximately 62% of the 2006 WSEC (Figure 1). Commercial sector modeled energy consumption is estimated at 69% of 2006 levels. Energy savings estimates for 2009 and 2012 are sourced from previous legislative reports – no values have been provided for 2015.



	2006	2009	2012	2015	2018	2021	2024	2027	2030
Residential	100%	82.7%	76.1%		60.5%				
Commercial	100%	86.8%	82.0%		69.6%				
Target: 8.75 % savings compared to the 2006 WSEC	100%	91%	83%	74%	65%	56%	48%	39%	30%
Target: 14% savings compared to each previous code	100%	86%	74%	64%	55%	47%	41%	35%	30%

Figure 1. Progress of the Residential and Commercial Energy Codes Towards RCW 19.27A Targets

This research shows that the WSEC has made steady progress toward the State goal of 70% energy use reductions in new code-compliant buildings. However, the commercial results indicate that the changes driven by the Washington State energy code alone may be lagging the targeted rate of improvements in the commercial sector. Furthermore, assumptions in the prototypes about magnitude and characteristics of unregulated energy uses (such as plug loads) may be skewing modeling results away from observed market practice. As code stringency increases, this trend will become more significant as unregulated loads become a larger percentage of total energy use. Subsequent research into building stock characteristics should increase the focus on how other non-code related changes in the building industry may have impacted the overall energy use of the commercial sector. This study has focused primarily on idealized energy use predictions from modeled prototypes, with only partial comparison to measured results for these building types. The available data on actual building performance and non-code building physical and operating characteristics is limited, yet these issues will become more critical to the assessment of code and policy progress toward 2030 building performance goals.

INTRODUCTION

In 2018, the Washington State Legislature recognized the need to establish a fixed 2006 code building energy use baseline in order to be able measure progress toward the goals of RCW 19.27A. The law states that the energy code shall be designed to construct increasingly energy efficient homes and buildings that help achieve the broader goal of building zero fossil-fuel greenhouse gas emission homes and buildings by the year 2031. For the State to be able to reach this 70% goal, a baseline energy consumption estimate is needed. This baseline will determine how to achieve the State's reduction targets.

The goal of this study was to model the average annual energy consumption of newly constructed residential and commercial buildings under the Washington State Energy Code (WSEC), both in 2006 and 2018. Outlined in this report are estimates of overall and detailed building sector energy consumption, intended for legislators and State Building Code Council (SBCC) members to gauge progress and set stringency requirements for upcoming code development. Also included are detailed processes for future consultants to reference, in order to repeat similar analyses of future code editions.

Phase Two of the analysis explores the sensitivity of key building types to changes in operating assumptions and unregulated loads, providing context for subsequent analysis to focus on aspects of building performance that are impacted more by market practice than by policy directives. Together the combination of policy directives and market response will determine the degree to which building performance achieves the energy use reduction targets.

Our modeling method for both the residential and commercial sectors follows the framework developed by the Regional Technical Forum (RTF), as well as processes used to develop the State's residential energy code. Historical studies including building stock assessments, metering studies, and surveys were used to inform the 2006 modeling inputs, which were then updated to show expected savings achieved by the 2018 code.

While builders and designers have the option to comply with code via several methods (i.e. prescriptive and whole-building performance methods), all buildings included in this study were assumed to comply through the prescriptive path only. This provides a well-defined list of inputs between any given analysis year and gives a clear view of code stringency.

When complying prescriptively, the 2006 code limited builders to a single pathway within both sectors. In 2018, by contrast, builders and design teams have a plethora of options to choose from, primarily within Section C406 and R406 of the energy code. These sections were introduced into the residential and commercial codes in 2009 and 2015, respectively, to bring increased savings while allowing for design flexibility. The various option paths are a great benefit to design teams and builders, but they also introduce more uncertainty when attempting to model energy savings.

For this exercise, assumptions regarding selected options under Section R406 in 2018 were informed by a Northwest Energy Efficiency Alliance (NEEA) funded Washington Residential New Construction Code study (NEEA, 2020), which defines code-compliance trends of housing permitted under Washington's 2015 residential energy code. Commercial measures under Section C406 were selected through design experience and engineering judgement regarding the most common and cost-effective solutions.

MODELING METHOD

In phase one of the analysis, the modeling process and selection of prototypes remained consistent with the framework developed by the Regional Technical Forum (RTF) and the Northwest Power and Conservation Council (NPCC) for energy forecasting for the region's utilities. The residential modeling process was the same as that used to develop and evaluate Washington State's residential energy code as well as to measure the effectiveness of other regional residential energy codes (NEEA, 2019).

The energy consumption of any given building is affected by several inputs, some predicable (i.e. code-mandated) and others irregular. In order to assess the impact of energy code changes on building performance, it is necessary to keep other non-code performance features constant, and this analysis was conducted in phase one of this project. However, to assess overall building progress toward performance goals that include non-code performance issues like plug loads and operating characteristics, these variables must also be assessed. That analysis is the focus of phase two of this analysis.

To identify energy code impacts on building performance, the study sought first to establish all the modeling constants, representing: specific building prototypes, distributions of characteristics (total floor area by occupancy, HVAC system type, location), schedules, and unregulated loads across the sectors. These details were found through various regional field surveys, building stock assessment studies, and RTF default assumptions.

After building prototypes were established and representative saturation values determined, then the code-mandated savings were modeled. The savings estimates are limited to regulated end-uses such as envelope insulation, heating, cooling, ventilation, lighting, hot water systems, and appliances (credits now honored in both codes for EnergyStar appliances). Explicit requirements (and optional measures) affecting the energy consumption for those end-uses can be found in the energy code and other compulsory documents, such as:

- 2006 Washington State Energy Code
- 2006 Washington State Ventilation and Indoor Air Quality Code
- 2018 Washington State Energy Code
- 2018 International Mechanical Code with Washington Amendments
- 2018 International Residential Code with Washington Amendments
- National Appliance Energy Conservation Act (NAECA)
- HB 1444 – Washington State Appliance Efficiency Standards

The team used EnergyPlus and Simple Energy Enthalpy Model (SEEM) programs, for the commercial and residential code respectively, to produce annual energy use estimates from all the regulated and unregulated loads. Batch modeling processes were used to complete over 200 residential and 90 commercial modelling runs to simulate each prototype under the various combinations of location, HVAC system, and code year.

At the conclusion of the phase one modeling, the commercial results were reviewed in the context of measured data from the CBSA regional field study, and from measured data from Seattle building stock reported under the Seattle Disclosure Ordinance. End use results were also compared to measured data from multiple sources. This review led to the conclusion that some building characteristics and predicted performance outcomes did not align well with measured data. In particular, assumptions in the prototypes about unregulated loads seemed to be driving anomalous outcomes in the predictions.

To address this, the project team undertook a second phase of analysis which was designed to identify additional data on commercial building use patterns that might better reflect actual building operation, and to explore the sensitivity of the modeling results to changes in input assumptions about unregulated building load characteristics. This analysis helped to identify key building operating characteristics that impact building performance and code outcomes outside of the narrow focus of the energy code itself. The results of the phase two analysis were used to recalibrate some of the prototype assumptions used in the modeling to more closely reflect measured outcomes.

RESIDENTIAL SECTOR

Residential Prototype Development

The residential building provisions for the WSEC apply to site-built one- or two-family detached dwellings, multiple single family attached dwellings (townhomes), and group R-2, 3, 4 construction (three stories or less). Prototypical representative characteristics include occupancy, house size, and ground contact type (slab, crawl, or basement).

The building prototypes used in this study are meant to reflect the varying sizes and styles within the residential sector. Except for the 5,000 sf home, all are standard analytical prototypes used by the RTF and NPCC to develop and evaluate energy forecasts and conservation plans for the region's utilities. In total, there are six distinct building prototypes for single family and two for multifamily, including townhomes (see Table 1).

Distributions of the prototypical foundation type, heating system, and building size are drawn from two important studies completed by RLW Analytics in 2007 which aimed to develop a representative sample of residential construction characteristics for single-family and low-rise multifamily homes built between 2004 and 2005 (RLW Analytics, 2007). Each prototype is assigned a weight in proportion to its frequency of occurrence in the building population (see the *Weighting* section below).

Table 1. Residential Prototype Characteristics

2018 WSEC Classification (Section R406)	**Small Dwelling Unit**		**Medium Dwelling Unit**					**Large Dwelling Unit**	**Group R-2**		
Prototypes	1344c	1344s	1500c	1500s	2200c	2200s	2688b	5000b	1000c	952c	952s
Building Type Single Family Detached (SF) or Multi-family (MF)	SF	SF	SF - Town-home	SF – Town-home	SF	SF	SF	SF	MF – Double Loaded Corridor	*MF – Garden Style*	*MF – Garden Style*
Heated Area (ft^2)	1,344	1,344	1,500	1,500	2,200	2,200	2,688	5,000	26,400	7,616	7,616
# of Units	1	1	2	2	1	1	1	1	24	8	8
Foundation Type	Crawl	Slab	Crawl	Slab	Crawl	Slab	Bsmt	Bsmt	Crawl	Crawl	Slab
Floors	1	1	3	3	2	2	2	3	3	2	2
Occupants/ Unit	2.0	2.0	1.7	1.7	2.7	2.7	3.5	4.0	1.7	1.7	1.7

The relatively limited number of HVAC options available to residential builders allows this sector to be well represented with four common HVAC systems as described in Table 2. Associated weights, derived from the 2007 RLW report, are shown in Table 4.

Table 2. HVAC System Types for Residential Prototypes

System Type	Description
GFNC – Gas furnace	Central gas furnace with distribution ductwork
GFAC – Gas furnace with air-conditioning	Central gas furnace and air-conditioning
HP – Central heat pump	Central heat pump with distribution ductwork and electric resistance backup
ZONL – Electric zonal heating	Electric baseboard heating. For 2018 analysis, houses with electric zonal required to have Ductless Heat Pump in main living area

WEIGHTING

Aggregating the modeling results down to representative energy consumption estimates (i.e. small home energy use or low-rise multifamily use) is referred to as weighting. The previously mentioned characteristic study (RLW Analytics, 2007) provides the most reliable documentation of residential building trends in Washington State and is sourced repeatedly in this study. A recent new construction code compliance study (NEEA, 2020), looking into 2015 WSEC code compliance paths for single family homes, has also been used to characterize current building trends and inform other modeling inputs for 2018 analysis.

The various distributions of prototypical characteristics derived from the RLW study such as house size, heating system type, and climate zone weighting, have been kept constant between code years. To substantiate the uniform weightings between 2006 and 2018, data sourced from the RLW Analytics study was corroborated against modern data, where available.

Climate zone weights (Table 5) sourced from the RLW (2007) study are in concordance with respective county-by-county population weighting values from 2010 Washington State census.[1] Also, data from NEEA's 2015 code compliance study suggest that the heating fuel breakdown for single family homes across the state is unchanged from the 2006 baseline – with gas heat is in 83% of homes and electric heating in 17% (NEEA, 2020). Though the data does suggest that more homes are installing ductless heat pumps as opposed to central air-forced heat pump systems.

By keeping these weights constant, code-mandated savings are better represented; but it must be noted that this assumption does imply that builders will always build the same types of homes, and that the energy code will not measurably affect a builder's choice of heating fuel. Building characteristic surveys are integral in capturing these potential changes to the market and should be used in future studies to gauge how the state is meeting its 70% reduction targets.

The following tables (Table 3 through Table 6) provide all constants used to weight the 140 individual modeling results down to representative values presented in this report.

[1] Washington Office of Financial Management. https://www.ofm.wa.gov/washington-data-research/population-demographics/decennial-census/census-2010/census-2010-data

Table 3. Residential Weighting by House Size

Prototype	SF 1344c	SF 1344s	SF 2200c	SF 2200s	SF 2688b	SF 5000b	SF 1500c	SF 1500s	MF 1000c	MF 952c	MF 952s
Weight	8%	2%	57%	10%	11%	2%	8%	2%	24%	31%	45%
	* Single family and multifamily each sum to 100%										

Table 4. Residential Weighting by Heating System Type

Heat Fuel	System	Single-family (SF)	SF – Townhomes	Multifamily R-2 (MF)
Gas	Furnace (no A/C)	55%	61%	0%
Gas	Furnace (w/ A/C)	28%	1%	0%
Elec	Air-source Central HP	13%	5%	0%
Elec	Electric Zonal (w/ DHP in 2018)	4%	33%	100%

Table 5. Residential Weighting by Climate Zone

IECC Climate Zone	Single- and Multifamily
4C (Seattle)	77%
5B (Spokane)	23%

Table 6. Single-family and Multifamily Weighting by Total Residential Floor Area

Occupancy Type	Weighting
Single Family	78.5%
Low-rise Multifamily	21.5%

Residential Building Modeling Inputs

Modeling inputs encompass all the variables that are applied to each prototype in order to reach the final annual energy consumption estimate. In large part, these variables influence regulated loads (heating, cooling, ventilation, lighting, and hot water), which are updated between different code analysis years to show code-mandated savings. These variables are either required by code or law and are irrespective of market trends or occupant behavior.

BUILDING COMPONENTS

Heating and Cooling

For heating and cooling equipment efficiencies (as shown in Table 10), these are defined by NAECA federal equipment standards and optional measures from Section R406 of the 2018 WSEC.

Lighting

Lighting runtime was modeled as 1.8 hr/day average for all fixtures (RBSA, 2014). There are no requirements for lighting in residential occupancies in 2006; therefore baseline assumptions were taken from the RLW (2007) reports, with incandescent bulbs (65 W/bulb) making-up the majority of lighting in single family and multifamily and only 15% of the installed bulbs qualifying as high efficacy lighting.

While Section R404 of the 2018 WSEC requires 90% of fixtures be high efficacy, the Washington Residential New Construction Code Study (WRNC) shows that 97% of the sampled lighting fixtures were high efficacy and primarily LED lighting (NEEA, 2020). This higher percentage LED lighting was modeled for all 2018 homes. High efficacy lighting was assumed to be compact fluorescent bulbs (14 W/bulb) in 2006 and LED lighting (10 W/bulb) in 2018.

Domestic Hot Water

Heating fuel source for domestic water heaters was assumed to match the space heating fuel source for all prototypes and analysis years. Equipment efficiencies and occupant densities were applied to baseline annual energy consumption[2] data sourced from the RBSA metering study (RBSA, 2014). A 10% reduction in daily hot water use was granted for low-flow showerheads[3] in the 2018 WSEC analysis due to the 2019 Appliance Efficiency Standards law.[4]

For 2018 code compliance, high efficiency water heating equipment measures were selected for all prototypes except for small dwelling units. Gas-heated homes were never assumed to select heat pump water heaters in any runs. Summary of water heating efficiencies can be found in Table 10.

Appliances and Plugs

Unregulated loads have a growing impact on annual energy consumption but largely remain outside the authority of the energy code, although the 2018 WSEC now honors credits for EnergyStar appliances and ventless dryers. These end-uses represent plug loads, consumer electronics (TV, game consoles, computers), cooking, and other appliances. There was no explicit differentiation between gas and electric use (i.e. cooking) within this category and all end-uses are incorporated as equivalent kWh/yr of electric energy use. Internal gains from these miscellaneous loads (lights, and occupants) are included in the SEEM modeling runs by averaging the daily internal gains and normalizing on an average hourly basis, but final annual energy use numbers shown are applied at a post-process calculation. The baseline energy use estimates used in this study are sourced from the 2014 Residential Building Stock Assessment (RBSA) Metering Study (RBSA, 2014) and are summarized in Table 9 for each predominant housing type.

---

[2] From 2014 RBSA: $Q_{DHW} = 570 + 1034*\#occ$ (kWh/yr)

[3] RTF UES Measure. https://rtf.nwcouncil.org/measure/showerheads

[4] Washington House Bill, as accessed 3/2020. http://lawfilesext.leg.wa.gov/biennium/2019-20/Pdf/Bills/Session%20Laws/House/1444-S2.SL.pdf?q=20200318222309

SECTION R406 MEASURES (2018 WSEC)

As previously mentioned, the 2018 code presents builders with many more options for prescriptive code compliance when compared to the 2006. In 2018, the option table in Section R406 defines different energy conservation measures and pairs them with a credit value. Each home, depending on size and occupancy type, is required to choose a minimum number of credits to comply with code. This section is used to increase the savings brought by each code cycle while allowing builders to have options for compliance. Table 7 provides a summary of each optional measure and associated credits within the 2018 code.

Table 7. Summary of the Option Table (Table R406.3) from the 2018 Residential Energy Code

Option	Description	Credits (All Other)	Credits (Group R-2)
1.1	Glazing at U-0.24	0.5	0.5
1.2	Glazing at U-0.20	1.0	1.0
1.3	5% UA reduction	0.5	N/A
1.4	15% UA reduction	1.0	1.0
1.5	30% UA reduction	2.0	1.5
1.6	40% UA reduction	3.0	2.0
1.7	Adv. framing, raised heel trusses (R-49) and glazing at U-0.28	0.5	0.5
2.1	3 ACH50 and 0.35 W/cfm whole-house fan	0.5	1.0
2.2	2 ACH50 and HRV at 65% sensible recovery	1.0	1.5
2.3	1.5 ACH50 and HRV at 75% sensible recovery	1.5	2.0
2.4	0.6 ACH50 and HRV at 80% sensible recovery	2.0	2.5
3.1	95% AFUE furnace	1.0	1.0
3.2	Air-source heat pump at 9.5 HSPF	1.0	N/A
3.3	Ground source heat pump at 3.3 COP	1.5	1.0
3.4	DHP at 10 HSPF	1.5	2.0
3.5	Air-source heat pump at 11.0 HSPF	1.5	N/A
3.6	DHP at 10 HSPF for entire dwelling unit	2.0	3.0
4.1	Deeply buried ducts	0.5	0.5
4.2	Ducts inside	1.0	N/A
5.1	Drain water heat recovery	0.5	0.5
5.2	Gas water heater at 0.8 UEF	0.5	0.5
5.3	Gas water heater at 0.91 UEF	1.0	1.0
5.4	Heat pump water heater at NEEA Tier I	1.5	2.0
5.5	Heat pump water heater at NEEA Tier III	2.0	2.5
5.6	Split-system Heat pump water heater	2.5	3.0
6.1	1,200 kWh/yr renewable energy generation (max 3 credits)	1.0	1.0
7.1	EnergyStar appliances and ventless dryer	0.5	1.5

While this study did not complete an economic analysis of the option table, the credits were selected on the basis of anticipated least first cost to the builder and reinforced by a recently completed field study of compliance paths through Table R406.2 of the 2015 WSEC (NEE,2020). Table 8 below lists the selected measures under Section R406 for this study. All measure packages include requisite Fuel Normalization credits from Table R406.2, aligned with the dominant space heating fuel/system type.

Table 8. Selected Measures from Table R406.3 for Each Prototype in 2018

Small Dwelling <1500 ft² (needs 3.0 Credits)						
Heating System	Selected Measures					
GFNC	1.3	2.1	3.1	4.2		
GFAC	1.3	2.1	3.1	4.2		
ASHP	3.2	4.2				
ZONL	2.1	3.4				
Medium Dwelling 1500 - 5000 ft² (needs 6 Credits)						
Heating System	Selected Measures					
GFNC	1.5	2.1	3.1	4.2	5.3	7.1
GFAC	1.5	2.1	3.1	4.2	5.3	7.1
ASHP	2.1	3.2	4.2	5.5	7.1	
ZONL	1.2	3.4	5.5	7.1		
Large Dwelling > 5000 ft² (needs 7 Credits)						
Heating System	Selected Measures					
GFNC	1.5	2.3	3.1	4.2	5.3	7.1
GFAC	1.5	2.3	3.1	4.2	5.3	7.1
ASHP	1.1	2.1	3.5	4.2	5.5	7.1
ZONL	1.5	2.2	3.4	5.5		
Multifamily (R-2) (needs 4.5 Credits)						
Heating System	Selected Measures					
ZONL (no DHP)	1.1	2.2	5.5			

To confirm if these measures are in fact the most commonly selected measures by builders, insight from a future modern building stock assessment would provide invaluable clarity into current building trends and help deliver a more accurate estimate of 2018 code savings.

Residential Building Modeling Process

Residential batch modeling relied on the Simple Energy Enthalpy Model (SEEM)[5] software for single-family and low-rise multifamily buildings. The analysis tool, used by the RTF and the NPCC for parametric energy analysis in the region, simulates hourly heating, cooling, lighting, and ventilation energy use from inputs including building shell characteristics, occupancy and building schedules, heating and cooling systems, duct parameters, and weather files. Energy consumption for all other end-uses was determined through engineering calculations supported by field studies and survey data.

[5] SEEM. https://rtf.nwcouncil.org/simplified-energy-enthalpy-model-seem

Besides regulated end uses (regulated by code and/or law), no inputs were changed between the code years. This includes building weights, internal gains assumptions, and miscellaneous plugs use for each prototype. Once all runs were completed, the results were consolidated down by the appropriate weights to representative values for the sector.

It should be noted that built-in assumptions about weighting of the population of different system types and other factors influence the magnitude of energy use and savings identified in the overall savings represented in Figure 2 below.

Residential Building Results and Analysis

The average site Energy Use Intensity (EUI), a measure of energy consumption normalized per square foot of conditioned floor area, for the residential sector in 2018 is 60.5% of that in 2006 (Figure 2).

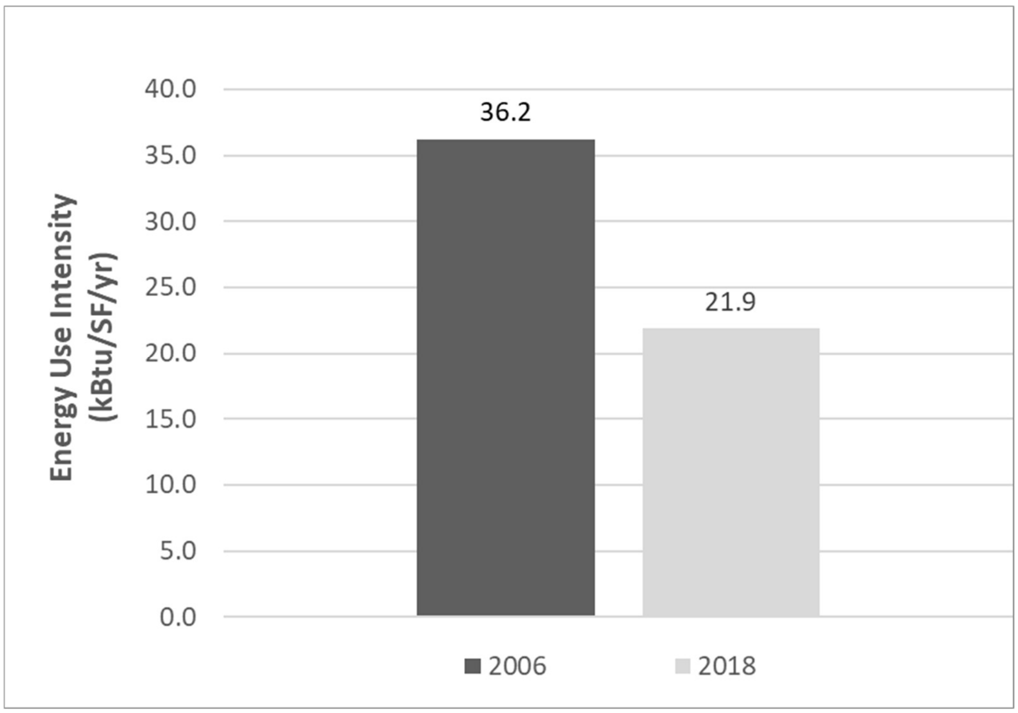


Figure 2. Residential Sector EUI by Code Year (2006 and 2018)

Figure 3 shows the EUI split into building types defined by the 2018 code within Section R406. Single-family medium dwellings represent 69% of the building types in the state and for this category the EUI in 2018 is 50% of that in 2006. Low-rise multifamily, representing 22% of all building types, show an EUI in 2018 that is 69% of 2006. Small homes show the least progress and remain at 80% of 2006 levels.

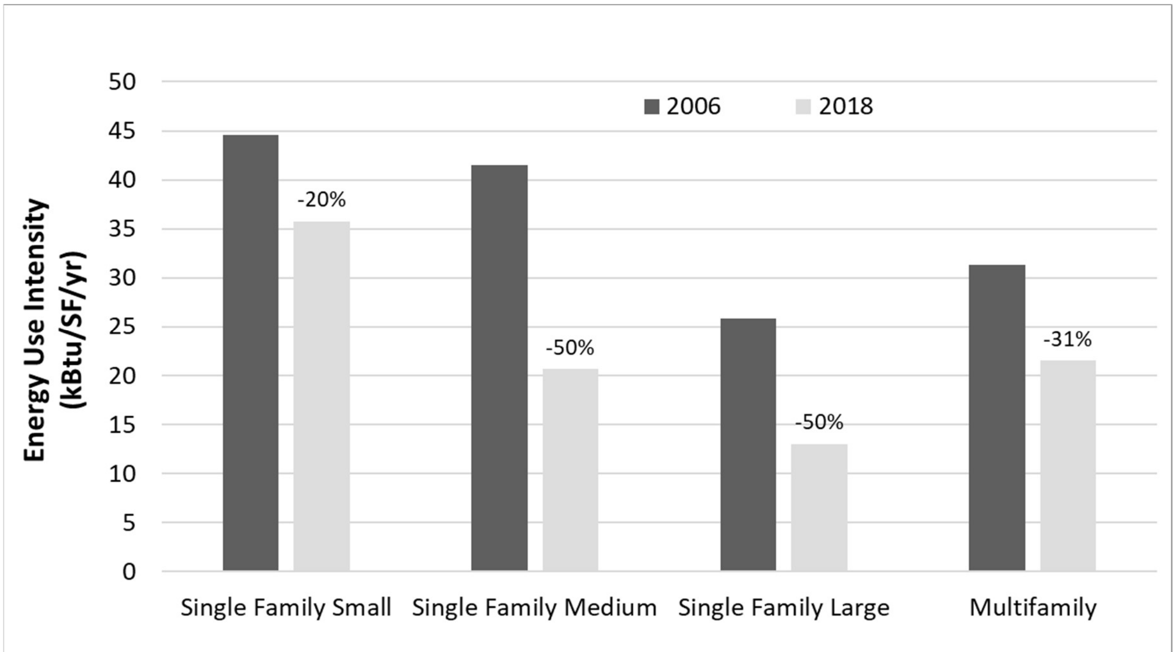


Figure 3. Residential EUI By Code Year and Percent Savings by Building Type

Figure 4 shows the EUI by end use for different building types. Lighting represents biggest percent reduction in end use, at 80% savings over the 2006 baseline. However, the greatest total energy savings are gained within the space heating end-use, where the average heating EUI in 2006 of 17.5 kBtu/sf/yr is reduced to 9 kBtu/sf/yr in 2018. Detailed modeling results can be found in Appendix B – Detailed Residential Modeling Results.

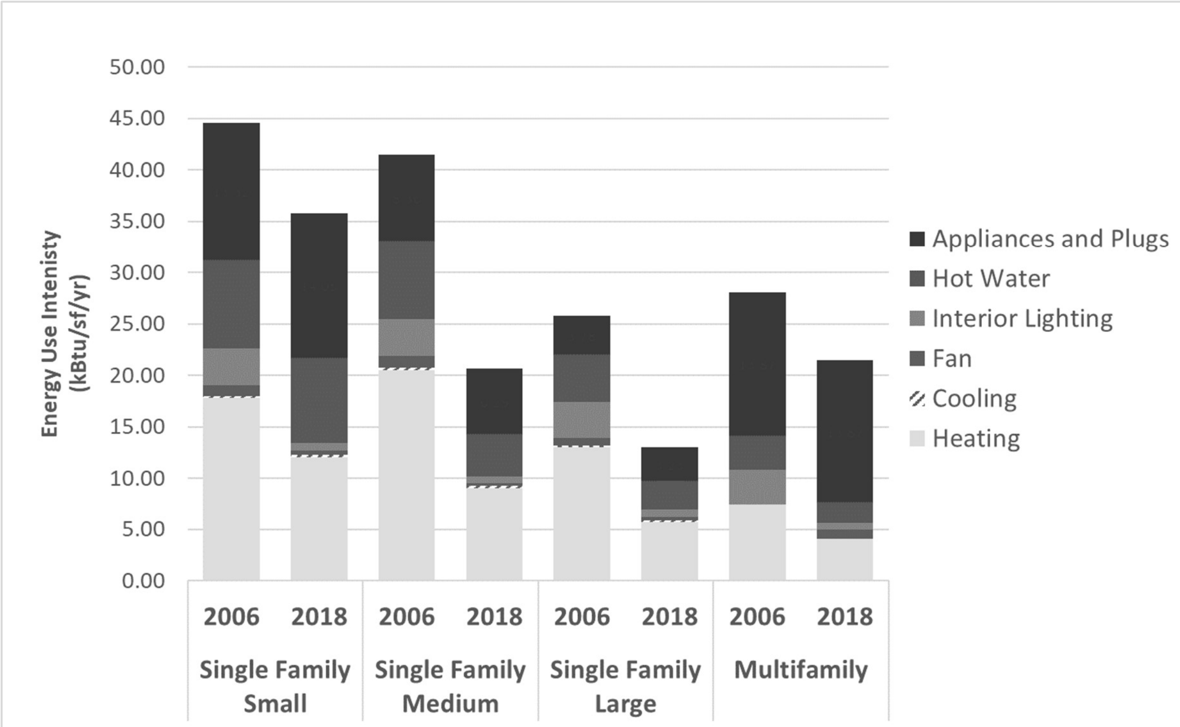


Figure 4. Residential End-use EUI by Building Type and Code Year

For prototypes which selected Option 7.1 (EnergyStar appliances and ventless dryer) from Table R406.3 in the 2018 code, an 840 kWh/yr savings was given for single family dwellings. Ventless dryers represent the bulk of these savings.[6] Modeled appliance and plug energy use is shown in the table below.

Table 9. Modeled Annual Energy Consumption of Appliance and Plug Loads by Housing Type by Year

Housing Type, Year	Appliance and Plug Energy Use (kWh/yr)
Single Family, Small - 2006	5,533
Single Family, Medium - 2006	5,533
Single Family, Large - 2006	5,533
Multifamily - 2006	4,121
Single Family, Small - 2018	5,533
Single Family, Medium - 2018	4,693
Single Family, Large - 2018	4,727
Multifamily - 2018	4,121

Other notable findings:

Required ventilation airflow rates dropped by 35% from 2006 to 2018, but fan modeled energy increases in 2018 due to a requirement for balanced ventilation systems in multifamily provided by heat recovery

[6] RTF UES Measures. https://rtf.nwcouncil.org/measure/clothes-dryers-sf-mh-and-mf-unit

ventilators which are modeled to run 24/7. However, a net energy savings is expected from reducing the heating load through ventilation heat recovery and increased envelope air tightness.

While cooling efficiencies and duct leakage rates improve between 2006 and 2018, these savings are diminished by a higher saturation of homes with mechanical cooling. In the 2018 WSEC, single-zone ductless heat pumps (DHP) are required in electric resistance heated single family homes through Section R403.7.1, and it was assumed that if heat pumps are present they will be used for cooling as well. This introduces a cooling load that was not measurably present in 2006. Nevertheless, DHPs are a heating measure in our region and this study shows 22% total energy savings over the 2006 baseline for electric resistance heated homes.

Federal minimum equipment standards have had little improvement since 2006. However, a 2007 study of residential characteristics suggested that standard practice was the installation of slightly more efficient furnaces, at 82%, than federal minimums, and this value was used in the baseline analysis.[7] Through Section R406 however, higher equipment efficiencies can be installed to achieve energy credits. These measures are often the most economical and easiest to implement (for example, condensing gas furnaces for space heating); therefore, equipment measures were selected for all 2018-compliant prototypes (NEEA, 2020). Table 10 below highlights the relative efficiencies of these select equipment measures.

Table 10. Federal Minimum Equipment Efficiencies compared to Table R406.3

System	2006 Federal Min Efficiency	2018 Federal Min Efficiency	2018 Table R406.3 Efficiency
Gas Furnace	78% AFUE[8]	80% AFUE	Option 3.1: 95% AFUE
Central A/C	13 SEER	13 SEER	N/A
Central Heat Pump	13 SEER, 7.7 HSPF	14 SEER, 8.2 HSPF	Option 3.2: 14 SEER, 9.5 HSPF
Water Heater (Elec, < 55gal)	0.90 EF	0.94 EF	Option 5.5: Tier III Heat Pump Water Heater[9]
Water Heater (Gas, < 55 gal)	0.57 EF	0.59 EF	Option 5.3: 0.91 UEF

The phase one study counted the 1,500sf townhome prototype (RTF standard) as a medium sized home (per size requirements in Section R406) and modeled the prototype with 6 efficiency credits. If the conditioned square footage was 1,499sf, then it would qualify as a small home and only need 3 credits (reducing the cost to comply with the 2018 code). Phase two analysis explored the impact of a townhome with reduced square footage and resulting decreased required energy credits. Analysis

[7] Table 111. Northwest Energy Efficiency Alliance. (2007). *Single-Family Residential New Construction Characteristics and Practice Study*. RLW Analytics.
[8] Per the RLW (2007) study, 2006 gas furnaces were modeled as 82% AFUE.
[9] NEEA. Advanced Water Heating Specification (as accessed March 2020). https://neea.org/our-work/advanced-water-heating-specification

suggests that although savings attributed to this specific prototype drop significantly, this prototype only represents ~5% of the total residential floor area, therefore overall residential-weighted EUI would be largely unchanged (21.9 vs 22.2 in 2018). But this is an example of why current market data is needed to inform the average size of all residential dwelling types to be modeled, in order to provide a more accurate estimate of energy savings in future code years.

In this analysis, assumptions about unregulated plug loads remained constant between 2006 and 2018 and are sourced from the metering study (RBSA, 2014). As regulated loads decrease through code advancement, the relative impact of unregulated loads on overall building performance increases. Appliance efficiency options being included in the 2018 code are a first step towards addressing this historically unmanaged energy load.

As shown in Figure 5, electric (heat pump homes) have a far lower heating EUI than their fossil gas counterparts. Even when applying the carbon emissions factors (from Table R405.3 of the 2018 WSEC), heat pump heating releases less CO_2 than on-site gas furnaces.

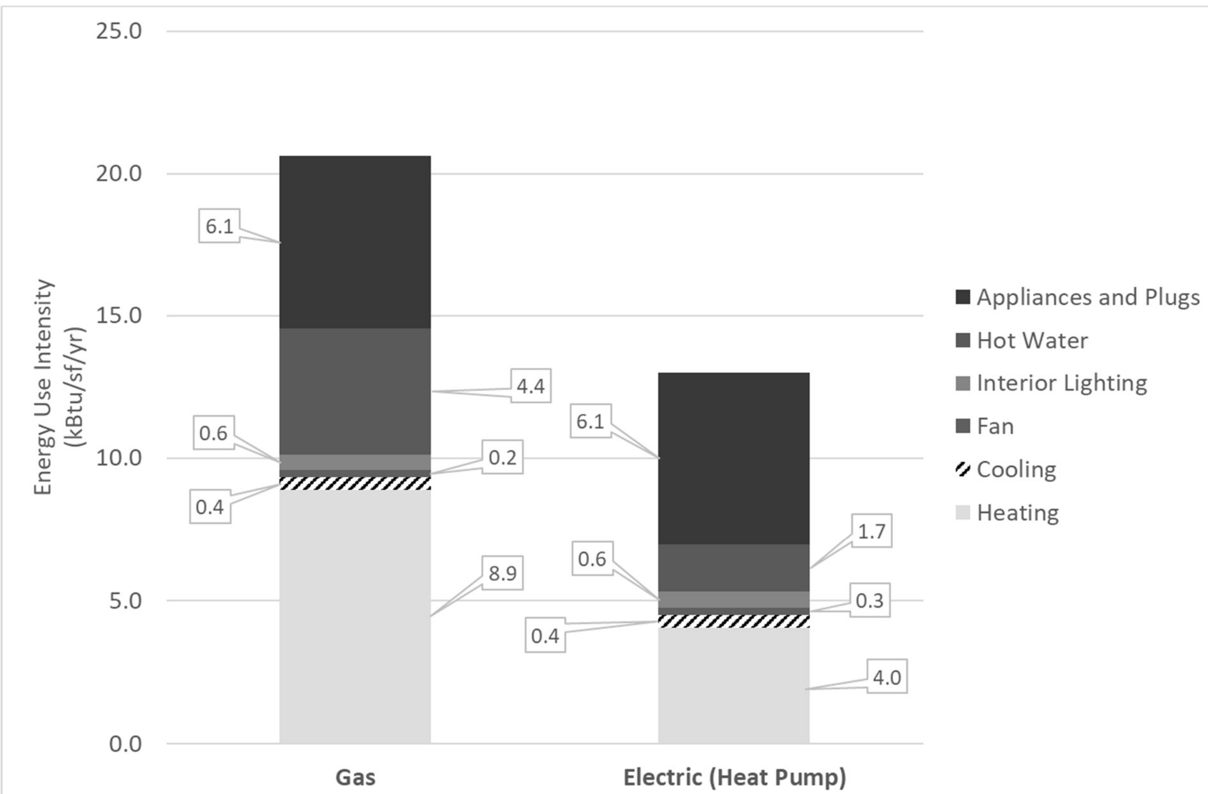


Figure 5. Average Modeled EUI of a Single-Family Dwelling (by EUI) in 2018 – Gas vs Electric

COMMERCIAL BUILDING ENERGY MODELING

This study is designed to establish a performance baseline for the 2006 WSEC, and to assess the savings that have been achieved in the energy code compared to that baseline in the 2018 version of the WSEC. Although the state building performance mandate is focused on overall building performance improvement, phase one of this study was designed primarily to identify the performance impacts of the WSEC on overall building performance. Assumptions about unregulated loads, and changes in market practice also have an impact on overall building energy performance, and phase two of this analysis was implemented to assess the magnitude of non-code and market impacts that could be identified. The final baseline estimates reflect a combination of modeled results for the prototypes and the inclusion of sensitivity factors reflecting building operational and unregulated load patterns.

The 2018 Commercial WSEC allows for two avenues for compliance: prescriptively and the Total Building Performance (TBP) path. The prescriptive path is a clearly documented approach to compliance: a building simply needs to meet all mandatory code sections to meet code. Whereas the TBP path, outlined in Section C407, provides an alternate compliance path for commercial buildings in which building energy models are submitted to demonstrate the proposed building has a lower modeled energy usage than a code-defined baseline building. It is intended that this path leads to energy savings that are roughly equivalent to the prescriptive path, however there is no distinct evidence that suggests that these two pathways have directly comparable savings.

Regardless, in the commercial sector, the vast majority of new buildings follow the prescriptive code to demonstrate energy code compliance. The City of Seattle, which has more performance submittals than most jurisdictions in the country, sees only about 5% of commercial projects using the performance pathway, according to Duane Jonlin at the City of Seattle. This analysis is focused on the energy performance impacts of the prescriptive pathway in the WSEC.

Commercial Building Prototype Development

As a starting point for this analysis, existing building prototypes developed by the Northwest Power and Conservation Council's (NWPCC) Regional Technical Forum (RTF) to estimate the energy savings potential of efficiency measures in buildings in the Pacific Northwest were used as the basis of the evaluation.[10] These basic prototypes have been used in multiple analyses over the years in this region and therefore provide consistent comparisons across various evaluations. The models are largely derivatives of the Department of Energy's (DOE) Commercial Reference Building models[11], revised to reflect data gathered in the 2014 Northwest Commercial Building Stock Assessment (Navigant, 2014) and the Northeast Energy Efficiency Partnerships (NEEP) lighting load shape project (KEMA, 2011).

The RTF suite of commercial building models, used as prototype models in this study, currently includes 15 commercial building prototypes. Three additional prototypes, representing mid-rise multifamily, high-rise multifamily, and outpatient healthcare included in the DOE CRB set were added to the analysis, together representing over 12% of building stock floor area in the region (Navigant, 2014). With all 18 prototypes, the commercial sector is believed to be well represented. The following building types were included in this study:

---

[10] RTF standard prototypes (as accessed March/2020): https://rtf.nwcouncil.org/work-products/supporting-documents

[11] U.S. Department of Energy (U.S. DOE), Energy Efficiency & Renewable Energy. *Commercial Reference Building models*. https://www.energycodes.gov/development/commercial/prototype_models

- Small Office
- Medium Office
- Large Office
- Stand-alone Retail
- Strip Mall
- Supermarket
- Primary School
- Secondary School
- Small Hotel
- Large Hotel
- Hospital
- Warehouse (non-refrigerated)
- Quick Service Restaurant
- Full Service Restaurant
- Outpatient Healthcare
- Mid-rise Apartment
- High-rise Apartment
- Residential Care

Additional description of building types is included in Appendix D – Commercial Building Type Descriptions; and Appendix E – Commercial Building Modeling Inputs.

The selection of HVAC systems for the commercial prototypes has a major influence on the modeling results since each system type has different influences on other end uses in the model, and therefore can result in significantly different annual energy end-use consumption estimates (such as fans, pump, compressors, boilers, and cooling towers if present). This analysis maintained a consistent ratio between 2006 and 2018 assumptions about system type distributions, and not all possible system types were modeled. Designers and engineers have an abundance of combinations to choose from, between primary heat source (gas, electric, air-source or ground-source heat pump), secondary heating source, distribution methods (air or hydronic), ventilation design (Variable Air Volume, dedicated outdoor air system, heat recovery, 100% outside air), and associated control strategies to manage these highly engineered systems. These variables introduce uncertainty into the results that can only be resolved with more detailed field studies to identify deployment rates of different system types, and any changes that might have occurred in system preference in the market between 2006 and 2018. Due to time and budget constraints and the large number of different prototypes and combinations in this study, only the most common HVAC systems were modeled.

Adding to the determination of HVAC systems are the requirements driven by climate, such as cooling for multifamily apartments buildings found commonly in Eastern Washington, but less so in Western Washington. For the purposes of this study, models with fossil-fuel space and water heating equipment are all assumed to use fossil gas, as it is the most common fossil fuel used for these applications in Washington State.

2006 HVAC SYSTEM SELECTION

For the 2006 baseline models, the project team sourced the HVAC system selections from the RTF prototypes and then corroborated those assumptions with a 2002-2004 field study of the nonresidential sector in the Pacific Northwest (Ecotope, 2008). This study documented building characteristics of a regional sample of commercial buildings permitted between 2002-2004, thus providing the clearest representation of commercial building practices for the 2006 baseline.

The comparison of the RTF HVAC systems to those recorded in the 2002-2004 nonresidential sector study revealed a few prototypes in which the single RTF HVAC system would not adequately capture the market in 2006. In these instances, the project team elected to model two scenarios that utilize the same HVAC system type but differ by primary heating energy source (fossil fuel or electricity), such as a packaged single zone rooftop unit with a gas furnace and an air-source direct expansion (DX) cooling coil or an air-source DX heat pump.

For the three prototypes not covered by the RTF suite of models (mid- and high-rise multifamily, and outpatient healthcare), the modeled HVAC systems include: the Department of Energy (DOE) default of water-source heat pumps in high-rise multifamily, packaged terminal air conditioners (PTACs) with electric heat and whole house exhaust fans for the mid-rise multifamily, and chilled water as opposed to air-cooled direct expansion (DX) cooling for outpatient healthcare. See Appendix C for a summary of the 2006 HVAC systems and associated saturations.

2018 HVAC SYSTEM SELECTION

The project team emphasized modeling consistent HVAC systems between each code year, and at a minimum, keeping each prototype's heating fuel source (electricity vs. natural gas) unchanged. The detail of heating fuel selection is crucial because any estimate of code-mandated energy savings would be heavily skewed by a switch from one to another (since heat pump efficiencies are higher than gas equipment). Historically the code has never addressed the selection of heating fuel, although for the first time, the 2018 WSEC incorporates the use of carbon emissions as the metric for determining compliance in two important sections of the code: Section C407: Total Building Performance and Section C403.1.1: Total System Performance Ratio (TSPR). Without field survey data to substantiate a significant shift in fuel sources used in new buildings, this analysis assumes that heating fuel source remains unchanged between analysis years. However, it does account for changes in heating source efficiency driven by the code, primarily TSPR, in that heat pumps have become the principal electric heating equipment as opposed to electric resistance. Future progress toward state mandated performance goals is likely to be heavily influenced by changes in fuel selection, so this issue will need to be tracked more closely in subsequent policy analysis.

Another important consideration in the selection HVAC systems is the introduction of the dedicated outdoor air system (DOAS) requirements in the 2015 WSEC for office, retail, library, fire station, and education occupancies. In the 2018 WSEC, DOAS requirements are expanded through Section C403.3.5 to cover more building occupancy types, along with balanced mechanical ventilation with heat recovery prescribed by Section C403.3.6 for the Group R-2 occupancy. Combined with the TSPR requirement, these two provisions will likely have a tangible impact on HVAC system selection for many building types.

In this study, 10 of the 18 prototypes are impacted by 2018 DOAS requirements with 8 of those 10 requiring compliance with TSPR. Aside from the inclusion of DOAS, the project team assumed the same heating/cooling equipment types as 2006 for all prototypes except for primary schools, secondary schools, medium offices, and large offices. For the 2006 vintage, these four prototypes were modeled with a multi-zone variable air-volume (VAV) system. A 2018 code-compliant VAV system is believed to be more costly than DOAS-compliant systems, and therefore, it was assumed these prototypes utilized DOAS with a zonal heating/cooling system.

In the end, the same overall heating and cooling system was modeled for 14 of the 18 total prototypes, with the significant energy-savings impacts of DOAS captured in all of the impacted prototypes. Eight prototypes' HVAC systems were altered for 2018 based on C403.3.5 Dedicated Outdoor Air Systems (DOAS): Small Office, Medium Office, Large Office, Stand-alone Retail, Strip Mall, Supermarket, Primary School, and Secondary School.

Two prototypes' HVAC systems were altered based on C403.3.6 Ventilation for Group R-2 Occupancies: Mid-rise Apartment and High-rise apartment.

Finally, eight prototypes kept the same HVAC system: Small hotel, Large hotel, Hospital, Warehouse (non-refrigerated), Quick Service Restaurant, Full Service Restaurant, Outpatient Healthcare, and Residential care. Although, it should be noted that energy savings from a heat recovery chiller was added to the hospital based on requirements from C403.9.2 Heat Recovery through Post Processing. A full list of HVAC System types for each prototype if provided in Appendix C.

WEIGHTING

Statewide floor area of commercial building types is sourced from the 2014 Commercial Building Stock Assessment (CBSA) (Navigant, 2014) with the distribution remaining constant between the two analysis years. Refer to Appendix D – Commercial Building Type Descriptions for comparison of modeled prototype occupancies to CBSA classifications.

Table 11. Statewide Commercial Weighting by Building Floor Area

Building Type	Fraction of Total Floor Area
Stand-Alone Retail	18.1
Warehouse	14.2
Large Office	10.7
Small Office	7.8
Medium Office	7.4
Mid-Rise Apartment	6.2
Primary School	5.7
Outpatient Healthcare	5.6
Large Hotel	5.2
Residential Care	4.8
Hospital	3.4
Strip Mall	2.6
Secondary School	2.4

Supermarket	2.4
Full-Service Restaurant	1.5
Small Hotel	0.7
High-Rise Apartment	0.7
Quick Service Restaurant	0.5

The CBSA does not have the required data to split total building floor area between the two primary climate zones in Washington; to protect building identity, no location data was recorded. Therefore, to split the total building floor areas between the Spokane and Seattle climate zones, an assumption was made that commercial building square footage was directly correlated to population. Based on census data, 75% of the population lives west of the Cascade Mountains (climate zone 4C) and 25% lives east of the Cascades (climate zone 5B) – this closely matches the residential climate zone weighting. While this is a simplified assumption, it is important to remember that this weighting was kept the same between each code analysis year, further reinforcing the focus on model-to-model savings.

As mentioned, any relevant HVAC weights were sourced from NEEA's 2002-2004 baseline nonresidential characteristics survey (Ecotope, 2008), with primary heating fuel sources remaining constant between analysis years (see 2006 and 2018 HVAC System Selection sections above). In this study, thirteen of the eighteen building prototypes were modeled with a single HVAC system. Due to the high costs of code-compliant Variable Air-Volume systems in 2018, paired with the rapid adoption of the market to variable refrigerant flow (VRF) heat pump systems (cost, savings, and simplicity of install and commissioning), the study assumed that VRF has replaced VAV systems for medium and large offices. While alternative heating/cooling systems can be paired with a code-required DOAS system, there is no current market data that would better inform a representative split between HVAC system types for offices (or any building type included in this study). Most importantly, energy savings associated with decoupling of the ventilation system is captured in the 2018 analysis. See Appendix C – Commercial HVAC System Types.

Commercial Building Modeling Inputs

A commercial modeling input summary for all modeled prototypes is summarized in Appendix E.

The first step in the modeling process was creating a baseline model based on the 2006 WSEC that included all energy code requirements for envelope, mechanical systems, service water, and lighting. In phase one of the analysis, all unregulated loads such as plug loads, cooking equipment, and refrigeration equipment were sourced from RTF and DOE prototype model defaults and held constant to focus specifically on building performance impacts within the scope of the WSEC.

Then a WSEC 2018 model was created by updating envelope, mechanical systems, service water, lighting, and adding in selected C406 measures. Changes in ventilation requirements from the Washington State Ventilation and Indoor Air Quality Code, required in 2006, and the 2018 International Mechanical Code are also included.

Table 12. Summary of Significant Code Changes Between 2006 and 2018 Commercial Building Models

Code Section	WSEC 2006 Baseline	WSEC 2018 Current Savings
Section C402 – Envelope	Table 5-1, 5-2: Thermal Envelope Requirements for Group R Occupancies by climate zone. Table 13-1, 13-2: Building Envelope Requirements by climate zone.	Table C402.1.4: Opaque Thermal Envelope Requirements. Table C402.4: Building Envelope Fenestration Maximum U-Factor and SHGC Requirements. C402.5: Air Leakage; 0.40 cfm/sf at 0.3 in wg.
Section C403 – Mechanical	Section 303: Ventilation per VIAQ. Table 14-1 (A-G): Equipment Performance	C403.2.2.1: Ventilation per IMC 2018. C403.3.2: Equipment Performance. C403.5: Occupancy classifications requiring DOAS. C403.5.1: Energy Recovery Ventilation with DOAS. C403.3.6 Balanced ventilation with 60% efficient sensible ERV required for Group R-2 occupancy
Section C404 – Service Water	Table 14-1 (A-G): Equipment Performance	Table C404.2: Minimum Performance of Water Heating Equipment
Section C405 – Lighting	Table 15-1: Interior LPD	Interior Lighting: 2006; 2018 Table C405.4.2(1), Table C405.4.2(2) Exterior Lighting: 2006 table 15-2; 2018 Table C405.5.3(2)

Starting in the 2015 WSEC and expanded in 2018, the WSEC includes Section C406 (Efficiency Packages), which requires new buildings and substantial alterations to include a total of six additional efficiency credits. Similar to the residential code, the package(s) selection is determined by design teams, and therefore all the possible code-compliant credit permutations result in a large number of models. Given the available time and project budget, this study was limited to modeling one combination of measures that achieve exactly six credits for each prototype. In theory, this assumption is justified by the fact that in 2018, C406 credit points better correlate to the energy savings they represent for each of the building occupancies classifications. Below is a list of the available C406 options and a very brief description, while Table 13 identifies the selected credits for each prototype.

Section C406: Efficiency Packages (refer to 2018 WSEC Table C406.1 for credit values)

Section C406.2: Efficient HVAC performance at 15% better than federal minimum requirements
Section C406.3.1: Reduced lighting power at 10% better than Section C405.4.1
Section C406.3.2: Reduced lighting power: 20% better than Section C405.4.1
Section C406.4: Enhanced lighting controls
Section C406.5: On-site supply of renewable energy by total conditioned floor area
Section C406.6: Dedicated outdoor air system (DOAS) for non-required building types
Section C406.7: DOAS at 80% sensible recovery and 0.5 W/cfm (for all building types)
Section C406.8.1 and C406.8.2: High-efficiency service water heating at COP 3
Section C406.9: High performance service water heating in multi-family buildings
Section C406.10: Enhanced envelope performance at 15% better UA than code minimum
Section C406.11: Reduced envelope air barrier infiltration tested at 0.17 CFM/sf
Section C406.12: Enhanced commercial kitchen equipment (Energy Star)

Table 13. Modeled C406 Measures by Prototype

DOE Reference Building	Occupancy Type	Additional Efficiency Credits Modeled
Small Office	B	2,5,11
Medium Office	B	2,5,11
Large Office	B	2,5,11
Stand-alone Retail	M	2,10
Strip Mall	M	2,10
Supermarket	M	2,10
Primary School	E	2,5,11
Secondary School	E	2,5,11
Small Hotel	R-1	1,2,5
Large Hotel	R-1	1,2,5
Hospital	Other	2,10
Warehouse (non-refrigerated)	Other	2,10
Quick Service Restaurant	Other	2,10
Full-Service Restaurant	Other	2,10
Outpatient Healthcare	Other	2,10
Mid-rise Apartment	R-2	6,11
High-rise Apartment	R-2	6,11
Residential Care	Other	2,10

New to the 2018 commercial energy code is *Section C403.1.1: HVAC Total System Performance Ratio (HVAC TSPR)*, an innovative endeavor to address inherent system efficiencies of various HVAC systems for impacted building types (office, retail, library, and education). The TSPR is the ratio of the sum of a building's annual heating and cooling load (in kBTUs) to the sum of the annual carbon emissions (in pounds CO_2) from energy consumption of the building's modeled HVAC system. The project team participated in the beta-version of the online modeling tool, developed by Pacific Northwest Laboratories, to confirm the selected 2018 HVAC systems are compliant with this new code section. The team found that the code-mandated Dedicated Outdoor Air Systems (DOAS) for these building types, with fan power and heat recovery efficiencies that match the TSPR defaults (0.82 W/CFM and 70% recovery efficiency) were two primary drivers to compliance with this section.

Commercial Building Modeling Process

Energy use of regulated loads was predicted by a combination of numerical simulations using energy modeling software—EnergyPlus (v9.0.1)—and engineering calculations. EnergyPlus was used to simulate heating, cooling, lighting, and ventilation energy use from inputs including building shell characteristics, occupancy and building schedules, HVAC systems, and hourly weather files.

Batch processing of the prototype models was performed using CBECC-Com[12], an open-source energy code compliance tool (BEE Software) funded primarily by the California Energy Commission (CEC) for California Title 24 (T24) code compliance. CBECC-com is a robust, easy-to-use interface for generating EnergyPlus input files (via DOE's OpenStudio software)[13], as it can be used to automate a number of steps, such as HVAC sizing runs, and populating HVAC equipment efficiencies and performance curves needed for simulation. CBECC-Com has been developed and used for performance-based energy code compliance modeling in California since 2013, and in addition to being tested and used by the design and engineering community for this purpose, it also actively used as a starting point for T24 Codes and Standards Enhancement (CASE) studies. In addition to being developed for T24 code compliance analysis, the Pacific Northwest National Laboratory (PNNL) funded a demonstration of using the CBECC-Com open-source framework for ASHRAE 90.1-2010 Appendix G modeling as part of developing the Performance Rating Method Reference Manual (PRMRM). [14]

O'Brien360 has been a core member of the CBECC-Com software development team since its inception in 2011. The version of CBECC-Com used for this study utilizes software code developed for performing ASHRAE 90.1-2010 Appendix G analysis, which has been adapted and enhanced by O'Brien360 for modeling the 2006 and 2018 WSEC prototypes. The EnergyPlus simulations performed using CBECC-Com were supplemented by side calculations and post-processing of modelling outputs in cases where either a) hourly simulations were not necessary for estimating the energy impacts, such as parking lot/garage lighting use, or b) where modeling the technology was not directly supported by CBECC-Com, such as heat recovery chillers.

The WSEC prototype models and results were developed in the following high-level steps:

1. Create the 2006 prototype from each building type, using the RTF or DOE prototype EnergyPlus input files (IDF) the starting point. These IDFs were translated into CBECC-Com input files using the OpenStudio software.

2. Populate the CBECC-Com models with the unregulated internal load assumptions and schedules defined in the RTF or DOE models, as well as the 2006 HVAC systems defined for this study.

3. Apply WSEC 2006 efficiency and ventilation provisions to the model inputs. These provisions included differences based on HVAC system type, and climate zone.

4. Modify the 2006 models to reflect 2018 efficiency and ventilation requirements, including the selected C406 efficiency packages.

5. Debug the simulations, i.e. review the calculated energy-end-use and other simulation outputs for consistency with expected values and make corrections/modifications to the models as needed.

[12] California Energy Commission's CBECC-Com project website. http://bees.archenergy.com/
[13] U.S Department of Energy OpenStudio project website.
https://www.energy.gov/eere/buildings/downloads/openstudio-0
[14] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-25130.pdf

6. Apply side calculations and post-processing of simulation results to arrive at the final energy performance calculations, prior to weighting by building type, HVAC system type, and climate zone.

POST PROCESSING CALCULATIONS

A small subset of energy code requirements could not be modeled through CBECC-Com directly, so separate calculations were performed to capture their effect on energy consumption for various prototypes. The five post-processing calculations needed were: exterior lighting, on-site renewables, hot water use reduction, heat recovery chillers in hospital, and condenser heat recovery in supermarket. Only exterior and garage lighting calculations were applied to the 2006 baseline models, whereas all five of the post processing were applied to 2018 runs.

Since the protypes did not include parking, parking lot areas represented as a ratio of the building-type conditioned floor area, sourced from the 2002-2004 baseline characteristic study (Ecotope, 2008), were applied. Lighting power density limits as defined in Section 1532 of the 2006 WSEC, were applied to the modeled parking area. For 2018, the lighting power was adjusted down based on the percent difference of allowed lighting power between the 2006 and 2018 WSEC. Results were then added to CBECC-comm models under a separate Exterior Lighting end-use with RTF default schedules.

For building types that were modeled to select the 2018 optional measure from Section C406.5: On-site renewable energy (see Table 13), a post processing calculation was completed to account for energy produced from solar photovoltaics as a separate, negative, end use to the results. Average annual solar production was average between Spokane and Seattle, as informed by PV Watts[15], to be roughly 1,100 kWh/yr/kW installed capacity.

Hot water flow reduction for low-flow fixtures in 2018 was applied to mid-rise and high-rise apartment models. This calculation followed the same process as the residential modeling (low-flow showerheads mandated by HB 1444 and flow reduction informed by RTF UES Measure workbooks). This resulted in a 10% decrease in hot water energy consumption.[16]

Post processing to estimate savings from adding a heat recovery chiller to the hospital model was done using hourly plant heating and cooling energy consumption. Section *C403.9.2 Heat Recovery from Space Heating,* in the 2018 WSEC, requires most hospitals to install heat recovery chillers. A heat recovery chiller is a water-to-water heating and cooling device that, in buildings with significant simultaneous heating and cooling, has potential to save a significant amount of energy. An hourly calculation was performed to determine the simultaneous heating and cooling occurring in the building that could be met through a heat recovery chiller, and the amount of additional heating that could be provided through heat recovery of exhaust air through the heat recovery chiller. This resulted in a 15 EUI savings

[15] https://pvwatts.nrel.gov/

[16] RTF UES Measure. https://rtf.nwcouncil.org/measure/showerheads

for both Seattle and Spokane climates. Many hospitals use a heat recovery chiller and condensing boilers to pass the Total System Performance compliance path (C407).

Condenser heat recovery is required per 2018 WSEC *C403.9.2.3 Refrigeration Condenser Heat Recovery* in supermarkets. Heat is recovered from refrigeration systems to heat hot water through desuperheaters (ASHRAE, AEDG Grocery Stores). Since most desuperheaters consist of a tank of water with a refrigerant coil used to preheat incoming hot water, they are limited to 100°F as the maximum preheat temperature reasonable achieved (Fricke, 2011). This corresponds to 56% reduction in hot water heating energy for supermarkets in this study.

This post processing effort only addressed energy usage changes covered by code requirements. In phase two of the analysis, additional post-processing was conducted to evaluate the impact of unregulated loads and operational variables in a sensitivity analysis.

SUMMARY

In total, 90 different combinations of building prototypes, HVAC systems, and climate zones were simulated in phase one of the analysis. To the maximum extent possible, the definition of model inputs was automated using CBECC-Com's 'ruleset' programming framework. The ruleset is compilation of software code, libraries, and tables that were brought together for this Washington code baseline project and read by the CBECC-Com software when processing the models. Once the CBECC-Com model input files and ruleset framework was set-up, the models were run as a "batch", meaning the assignment of inputs, and running of all 90 simulations was performed automatically by the software, taking roughly five hours. The results are output by the program to a CSV formatted data file, which was processed into the final results as presented in following sections.

Commercial Building Analysis and Results

CODE TO CODE COMPARISON

A key goal of this phase of the analysis was to understand the stringency of the 2018 WSEC, and the degree to which this code was delivering performance improvement when compared to previous code versions. In order to evaluate code stringency, it is necessary to keep unregulated loads constant, so that the analysis is focused on the impact of code requirements themselves. This also allows for comparison with previous code stringency studies to assess code progression. Phase One of this analysis focused on this comparison using the same prototypes and assumptions as previous code studies, to provide a comparable analysis of code progress.

COMPARING 2006 AND 2018 WSEC RESULTS

The analysis of WSEC 2018 compared to the 2006 code baseline indicated performance improvement in all building types. Figure 6 shows the change in EUI predicted for each code building prototype based on the modeling assumptions used in the study.

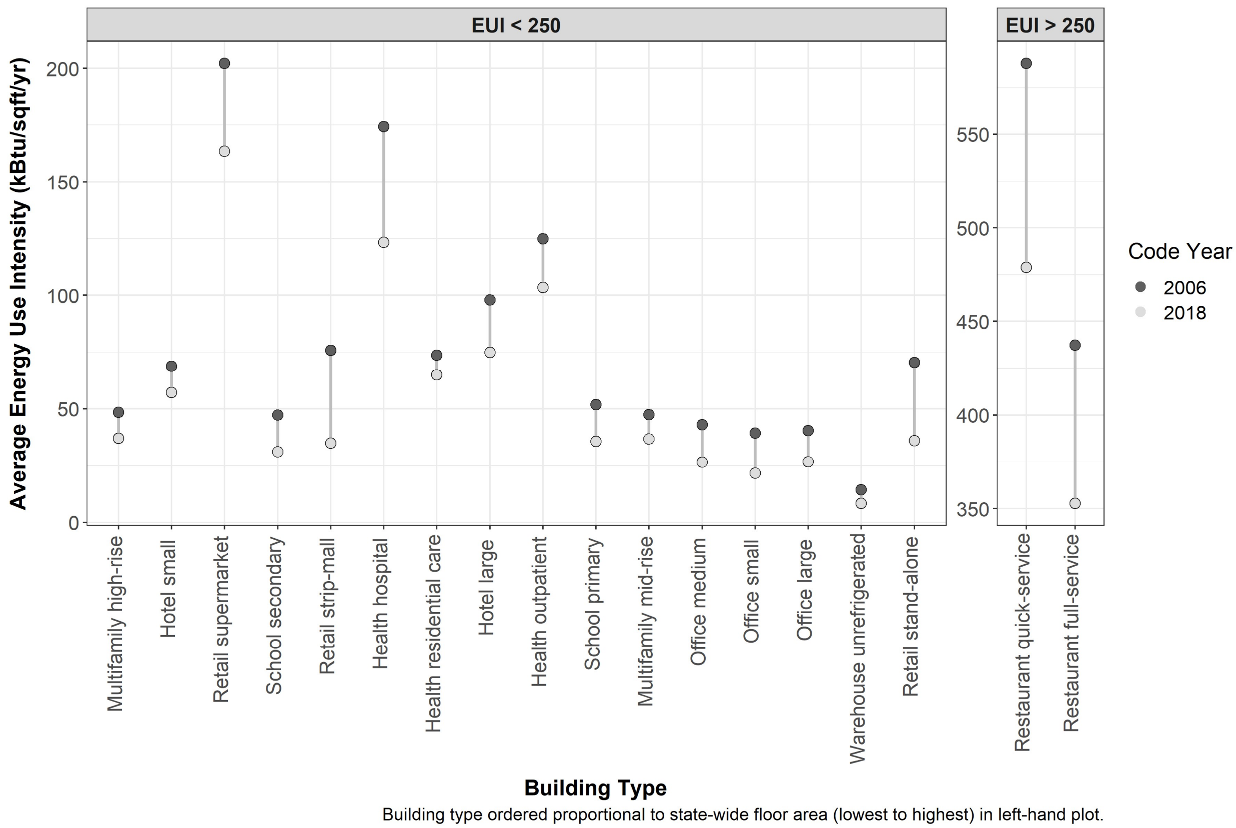


Figure 6. Commercial Modeled EUI Comparison by Building Type by Code Year

Although all building types have shown some reduction in energy use intensity from 2006 to 2018, some reductions have been of greater magnitude than others. Figure 6 above shows the specific predicted change in EUI between 2006 and 2018 from this analysis for each prototype, along with the percent change in total energy use. Total floor area represented by each building type in Washington is also indicated.

Part of this difference is the result of code adoption of significant performance improvement requirements that apply unevenly to different building types. For example, the requirement for DOAS ventilation systems has a significant energy impact on office buildings but little or no impact on multifamily and warehouse buildings. The difference can also be attributed to the fact that these building types have different levels of unregulated loads so code measures that impact regulated building features have a smaller overall energy impact on total load in some building types compared to others. This variability is exacerbated by the fact that unregulated loads interact with regulated loads differently in different building types. For example, if unusually high equipment loads are assumed in the modeling, the internal gains from this equipment have an outsized impact on heating and cooling loads, while project types with lower internal gains are not affected to the same degree.

Table 14. Energy Use Intensity and Percent Change by Commercial Building Type - 2006 and 2018

Building Type	2006 EUI	2018 EUI	% Change EUI	Fraction of Total Floor Area
Retail stand-alone	70	36	-49	18.1
Warehouse unrefrigerated	14	8	-42	14.2
Office large	40	27*	-34	10.7
Office small	39	22*	-45	7.8
Office medium	43	26*	-38	7.4
Multifamily mid-rise	47	37	-22	6.2
School primary	52	36*	-31	5.7
Health outpatient	125	103	-17	5.6
Hotel large	98	75*	-23	5.2
Health residential care	74	65	-12	4.8
Health hospital	174	123	-29	3.4
Retail strip-mall	76	35	-54	2.6
School secondary	47	31*	-34	2.4
Retail supermarket	202	163	-19	2.4
Restaurant full-service	437	353	-19	1.5
Hotel small	69	57*	-17	0.7
Multifamily high-rise	48	37	-23	0.7
Restaurant quick-service	588	479	-19	0.5
*Includes solar offset From Section C406.5				

The modeling results for all of the prototypes are combined into a weighted overall value in Figure 7. The individual prototype results are weighted by population as described earlier in the report, and this represents the weighted performance of the entire commercial sector, comparing 2006 code baseline results to the 2018 WSEC.

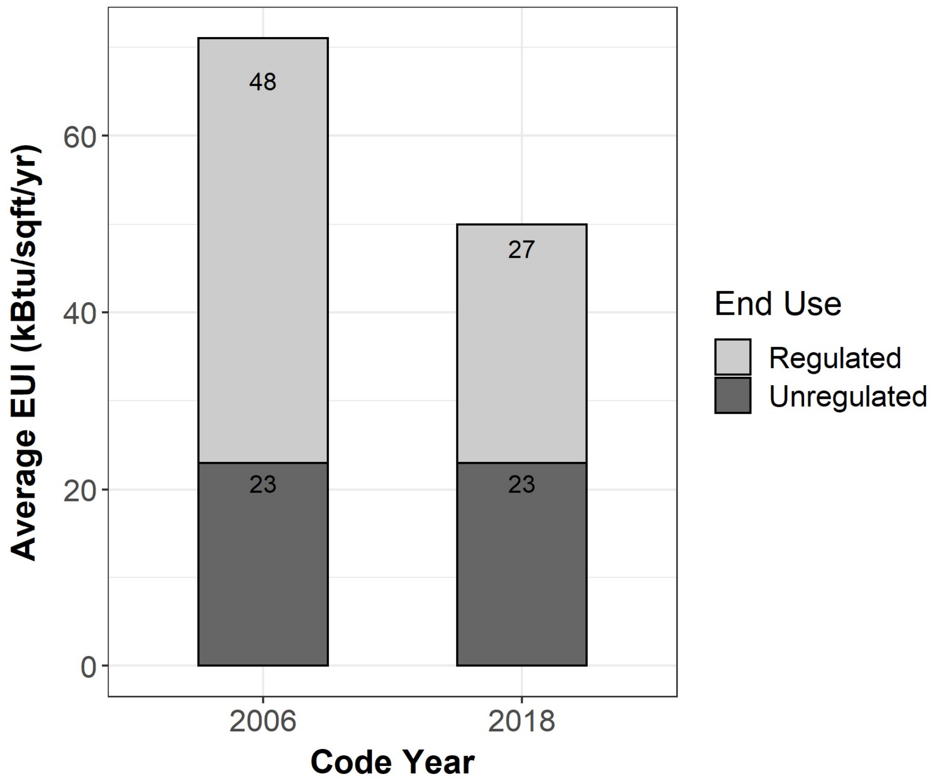


Figure 7. State Comparison Including Regulated and Unregulated End Uses

The overall improvement in code stringency is approximately 30% (including some PV offset from option measures modeled under Section C406.5, as shown in Figure 7. This figure also shows that unregulated loads were assumed to remain unchanged between the two code cycles, emphasizing that the impact of unregulated loads on overall building performance patterns is evolving. For Washington to achieve a 70% reduction in overall building energy use, strategies to reduce unregulated energy use must be identified and deployed.

COMPARING THE 2006 BASELINE TO MEASURED RESULTS

To provide context for the modeling analysis of the 2006 WSEC, data from other modeling studies and measured data was compared to the results for each building type. Figure 8 below shows this comparison, including modeled analysis of ASHRAE 90.1 2013, data from the Commercial Building Stock Assessment (CBSA), and benchmarking data from the City of Seattle in 2016.

The comparison to ASHRAE 90.1 (based on determination analyses conducted by PNNL of this code version) allows a comparison of the WSEC 2006 to the stringency of national reference code values of a similar stringency. The code community in Washington has generally considered the state code to be more stringent than the contemporary national code version. This data bears that out for some, but not all, building types when the WSEC 2006 is compared to ASHRAE 90.1-2013.

Comparing the results to actual measured performance data is also an informative touch point. In this graph, data from the Commercial Building Stock Assessment and from the Seattle Disclosure Ordinance is also compared for each building type (when available). Note that the CBSA and Seattle data represents buildings of all ages, so the measured data is not necessarily a direct reflection of code impact. Nevertheless, variance of modeled data from measured results suggests that additional consideration of building performance predictions is warranted. This is the sensitivity analysis generated in Phase Two of this project, and described below.

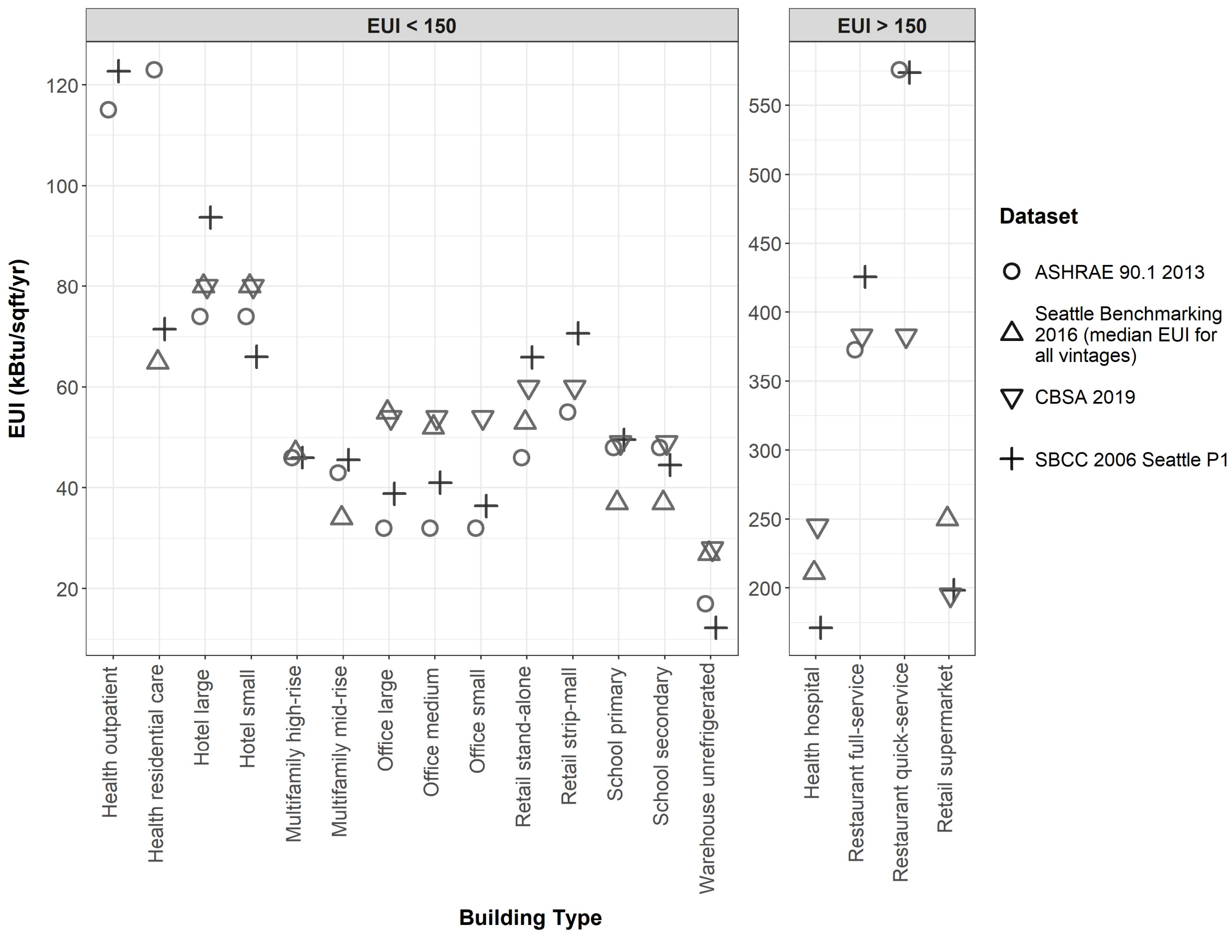


Figure 8. Phase One 2006 Commercial Building Modeling Results (4C Climate) with Comparison Datasets

Although patterns of higher and lower energy use between building types show consistency across most data sets, the data shows significant variability within several prototypes, and more moderate variability in a wider range of prototypes. There are multiple drivers of this variability. For example:

1. Certain prototypes may be defined with substantially different components and operating characteristics in the different data sets. For example, restaurant, retail, hospitality and health care energy use is substantially driven by occupancy and process load characteristics. In some cases, retail may include refrigeration, while in restaurants the type of food served and number

of diners can significantly impact energy use modeling and outcomes. Hotels and residential care facilities can include a range of different services that vary widely among individual facilities. In large office (and multifamily) buildings, large window area or the presence of onsite servers can result in significant variability in energy use between buildings. A single prototype is not able to capture this range of potential outcome, and variability among different analyses and measured data is expected.

2. Key assumptions about unregulated loads may vary between analyses and may differ significantly from actual buildings. Since unregulated loads represent the largest end use in most of these building types, modeling assumptions about these loads have a major impact on prediction results. Actual buildings have a wide range of operating characteristics with reflect to unregulated loads, and there is not good data to suggest that the RTF prototypes have identified a mean value for unregulated loads as a basis for analysis. So we cannot expect the modeling outputs to directly align with mean measured performance. These factors suggest that a range of operating parameters should be considered in considering the implications of modeling results.
3. Modeling does not capture operating problems like equipment malfunctions, control failures, or unanticipated zone interactions. These factors contribute to wide variation in individual building performance, compared to modeled predictions.

To explore these issues in more detail, a second phase of analysis was conducted to determine the sensitivity of performance outcomes to performance and operational variables that are not driven by code stringency. The analysis focused on a subset of building types that individually represented a significant percentage of total building sector energy use, and was targeted at the 2006 baseline dataset. This sensitivity analysis is described below.

Phase Two Sensitivity Analysis

In Phase Two of this analysis, specific building performance factors were explored that might introduce expected variability into the modeled results described above. In particular, building characteristics driven by occupancy and operation, rather than by code requirements, were targeted to better understand performance variability between models and measured data.

The sensitivity analysis was also conducted to assess the impact of unregulated loads on energy end use in various building types. For example, overly aggressive assumptions about plug loads can artificially reduce apparent heating energy use, and therefore incorrectly reduce code focus on this end use as a pathway to performance improvement.

RESEARCH ON BUILDING OPERATIONAL CHARACTERISTICS

The project team searched for research papers and data sources on building operational characteristics that might support or diverge from assumptions used in the phase one prototype modeling. The research focused on analysis of unregulated loads, lighting power densities, window to wall ratios, and HVAC equipment and operations characteristics. A summary of the data sources identified in this process is included in Appendix F of this report. The research was used to identify a range of values for these variables that could be modeled to assess reasonable performance ranges for the buildings.

In the research phase, Ecotope was also provided with updated modeling analysis being developed for the Regional Technical Forum (RTF) by *Big Ladder Software* on improvements to regional prototypes. This analysis included extensive explorations of the impact of different building characteristics and operating assumptions on prototype building performance. This work provided a valuable addition to the sources and analysis accumulated by Ecotope.

ADDITIONAL MODELING

The research findings above were used to modify specific aspects of the prototype models to determine the degree to which occupant and operational factors (non-code characteristics) drove building performance results, in a way that might help explain potential variation of modeled results from measured data, and to better understand the interaction of unregulated loads and regulated end use energy. Additional modeling conducted by OBrien360 was used to explore these issues further, and to better understand the implications of the modeling results.

KEY FACTORS IN SENSITIVITY ANALYSIS

A key aspect of this analysis is to determine the degree to which different assumptions about unregulated loads impact regulated and overall building energy use, to improve the accuracy of baseline performance predictions, and so that policy assumptions about the 2006 baseline can take into consideration the impact of unregulated loads on policy and code goals. Changing assumptions about unregulated loads not only affects the anticipated total energy use of the buildings, but can have significant impact on regulated loads and end uses in the building as well. Accurate information about end use patterns is critical to setting effective code improvement priorities for subsequent code versions.

Based on the research and data reviewed, the team identified specific building loads within key building types for analysis. Most of the analysis focused on unregulated loads, but the impact of lighting power density, window area changes, and control malfunction were evaluated as well for some building types. Unregulated loads include plug loads and other miscellaneous electrical loads, schedule and set point adjustments, kitchen energy use, domestic hot water consumption, and outdoor air flow. A realistic range was established for each sensitivity modeling input. Those ranges were used to establish which building characteristics have the most impact on energy use. Important building characteristics are described below by building type.

Multifamily Buildings

Sensitivity analysis found major impacts from varied use rates of domestic hot water, receptacles, and lighting. Domestic hot water use and receptacles, both unregulated by code, had the most significant impact on energy usage. Lighting, which is partly regulated, followed.

Although significant variation is possible, Phase One modeling results aligned closely with metered data, and modeling inputs aligned closely with research on unregulated loads. As a result, little adjustment was made to the energy use in multifamily buildings in Phase Two. But given the potential range of impact that unregulated loads have on total energy use, alignment between modeled and metered EUI does not necessarily suggest that the end use breakdown predicted by the modeling aligns with metered outcomes.

Schools

In the school building types, variations to receptacle loads, kitchen equipment, and setpoint had the largest impact on energy usage. Receptacle loads in the original prototype modeling did not align with research conducted in Phase Two, nor did it reflect recent school project experience by Ecotope. However, the total energy use predicted for schools in Phase One was not far from measured data. Modifications to unregulated load characteristics based on published field research do not significantly change the predicted EUI of this building type. However, these modifications lead to a more sensible predicted energy end use distribution that better aligns with performance data from regional studies. This improves the basis for considering impacts of individual code measures on this building type.

Significant reductions in receptacle loads were analyzed, reflecting results of research on school building use patterns and load adjustments. Inaccurate assumptions about plug loads can significantly skew results on the significance of regulated loads in overall building energy use. To highlight the significance of this issue, Ecotope evaluated the impact of a range of assumptions about interior equipment loads on the primary school building prototype. Varying interior equipment loads through a range of equipment density can change the anticipated heating energy needed in the primary school prototype by a factor of four. This result is shown in Figure 9. At the high end of interior equipment values are the assumptions provided by the RTF for this analysis. At the low end are interior equipment values aligned with a recently built school project completed by Ecotope.

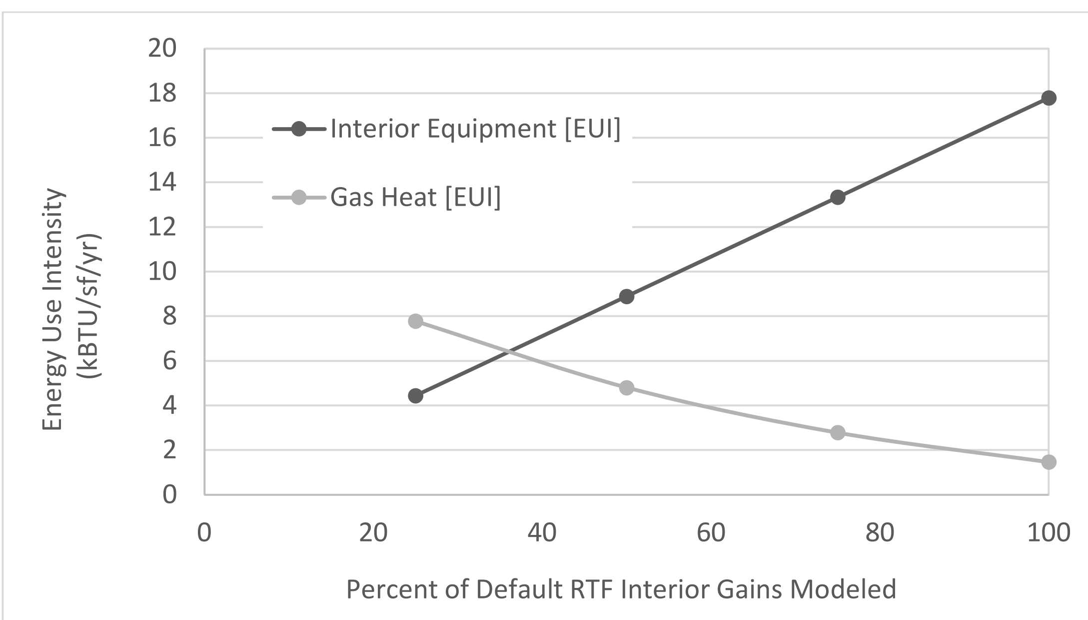


Figure 9. Impacts of Internal Gains on Heating Energy Use for the Primary School Prototype with Gas Heating

Office

Receptacles, outdoor air flow, and setpoint had the largest impacts on energy use in office building types. Office energy use was low in comparison to metered data. Air flow and setpoint can explain a significant amount of the variation but other factors such as poor equipment operation and window to wall ratio can also have significant impacts on total energy use, and variance from modeled results. Equipment operational anomalies were accounted for in this study based on research from DOE and PNNL on the energy impact of operational and control problems. But engineering experience with certain system types, such as VAV controls suggest that more significant adverse energy impacts from equipment operation are not uncommon. Though difficult to quantify based on currently available data, this issue is likely to contribute significantly to variability seen between predicted and measured performance in this building type.

Window to wall ratio (WWR) is another building characteristic that can have significant impact on building energy use. Although window performance is regulated by the energy code, the amount of glazing allowed is more flexible, subject to some limits by the code, but not specifically proscribed. To assess the impact of different levels of WWR, the medium office prototype was modeled with a range of different WWR's, ranging from 15% to 60%. This reflects a fairly typical range of outcomes seen in the building stock. Figure 10 below shows that changes to WWR affect different building energy end uses by highly variable amounts, and these impacts can be significant. Although it is clear that WWR has a significant impact on building energy use, no information was available about measured WWR characteristics in the building stock on which to base modifications to this variable, so it was not included in the adjustments to this prototype in the sensitivity analysis.

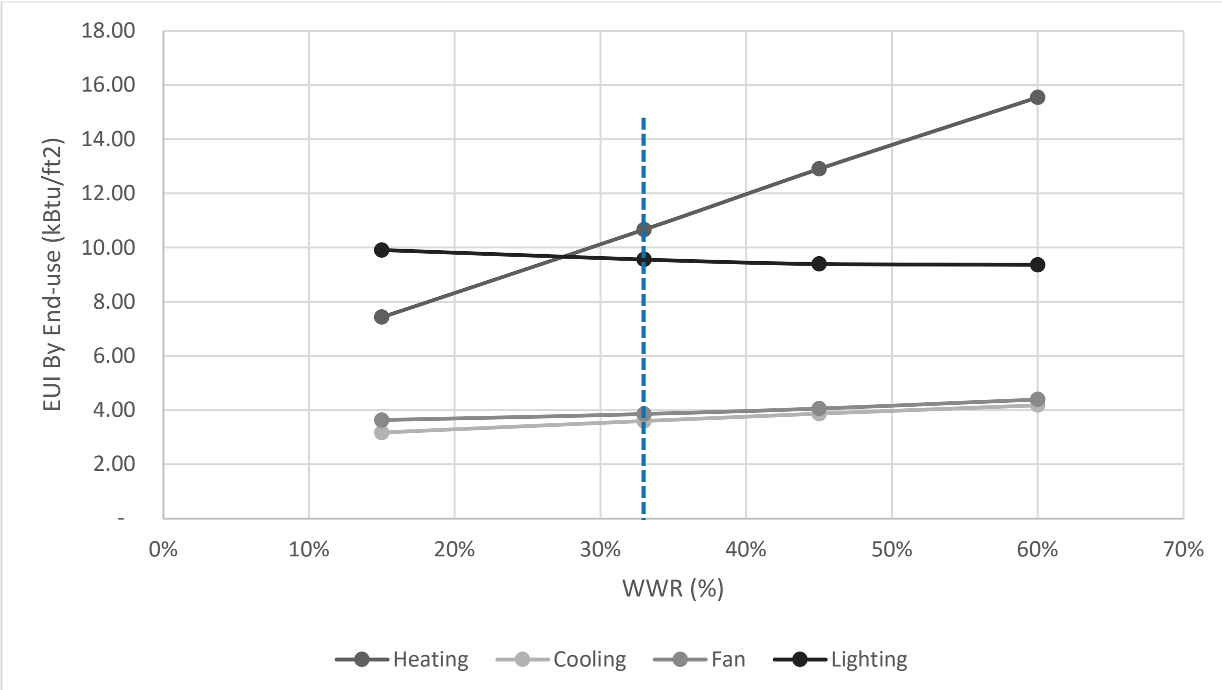


Figure 10. Impact of change in WWR on end-use energy for 2006 Medium Office prototype (dashed line shows modeled baseline WWR value)

Modeling large office buildings is notoriously troublesome, because multiple unregulated variables can impact energy use. In this case, the presence or absence of computer server equipment and other plug loads drive significant variation in energy use. As described above, window area ratio is also a significant variable. Control issues also play a role in office energy use with simultaneous heating and cooling and zone interaction representing known adverse impacts on office energy use. Research by PNNL identified adverse energy impacts from building control problems ranging from 5-9% of total building energy use[17]. (A 5% factor is included in the sensitivity range shown in Figure 10 above.) Optimistic assumptions about office building energy use should be tempered by an understanding that measured performance of office buildings is often significantly worse than is typically modeled using determination analysis protocols such as this study.

Unregulated loads, window area, and control issues can all contribute to increased energy use in this building type. Measured data tends to suggest higher energy use for this building type than modeled predictions. This suggests that some combination of these issues is typical in the office building stock. Although we have implemented some modifications to these assumptions for this building type, these changes alone do not explain the gap between predicted and measured performance. Subsequent work

17 https://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf

to better assess performance issues in regional office buildings would improve confidence in office building performance predictions.

Hotels

The prototypes suggest significant operational differences between large hotels and small hotels. This could be due to the inclusion of more features and services at large hotels, such as pools and restaurants. The measured data from CBSA and Seattle do not differentiate hotel performance by size, and the mean measured EUI performance value lands in between the predicted values for large vs. small hotels.

To assess variability in hotel prototype energy use, hot water consumption, receptacle loads, lighting, and kitchen equipment alterations were considered. The largest impact on performance predictions was from variations to DHW consumption and receptacle loads, followed by lighting loads. (Common area lighting is regulated by code in hotels; in-room lighting is not.) A moderate impact on energy use in the large hotel prototype was seen with changes to assumptions about kitchen equipment.

Although these variables impacted overall hotel energy use, field information about hotel use patterns and unregulated loads was not available. Since the predicted hotel energy use aligned well with measured data, no adjustments were made to this prototype in the baseline analysis.

Residential Care

Residential Care buildings showed similar end use patterns to multifamily buildings when unregulated loads were adjusted. This prototype was particularly sensitive to changes to assumptions about domestic hot water consumption and lighting loads. A key potential difference from multifamily buildings is that residential care facilities may be more likely to incorporate central HVAC systems, and occupant-driven lighting loads may see lower variability than the multifamily sector. Central equipment operational factors may be a bigger driver of variability in this building type than in multifamily. No data on unregulated load patterns in residential care facilities could be identified on which to base specific adjustments to performance predictions, though the degree of care offered by the facility is likely to drive variations in unregulated load intensity.

Restaurant

Unregulated energy use is the primary driver of energy use in these building types. Unsurprisingly, food service energy use is extremely dependent on assumptions about kitchen equipment configuration and use intensity. Kitchen equipment use is the primary end use in this building type. Domestic hot water use and plug loads are directly related to kitchen equipment use but modeled separately, and also show significant variable impacts on total building energy use. This building type shows the largest variation in energy use from adjustment to unregulated load intensity of any of the prototypes, and in practice metered data for restaurants is similarly variable.

Hospitals

Medical buildings in general are represented by a very wide range of service levels, represented by significant differences in the amount and energy intensity of equipment used to provide different types of medical services. These ‘process’ loads represent a significant fraction of hospital energy use, and make sector characterization challenging.

Retail (Strip mall and stand-alone)

Changes to building setpoint showed the biggest impact on predicted energy use in this building type. Assumptions about plug load had the second largest impact. Like food service, retail energy use characteristics can vary widely between individual stores.

Supermarket

In this building type, variations to refrigeration equipment and setpoint have largest impact on predicted energy use. There is little research available to support better calibration of unregulated loads in this building type, however, Phase One modeling results are close to available metered data.

Warehouse

Measured data for warehouse buildings suggests energy use well above the values predicted in this study. This is most likely because the CBSA data includes refrigerated and non-refrigerated warehouse in a single category, skewing EUI upward. This building type was not addressed in Phase Two of this analysis.

RANGE OF PERFORMANCE

Taken together, the sensitivity analyses conducted on each building prototype results in a range of energy use impacts for each building type analyzed. For some building types the range of potential energy use outcome was significant, while for others the performance band was relatively narrow. The combined results for all building types analyzed is shown in Figure 11. The range shown represents an average of the range of energy impacts of different input assumptions on performance outcome for each project type, treating each load impact as an independent variable. The individual data point for each building type shows the 2006 EUI baseline for each project type calculated in the previous analysis as well as the adjusted Phase Two result.

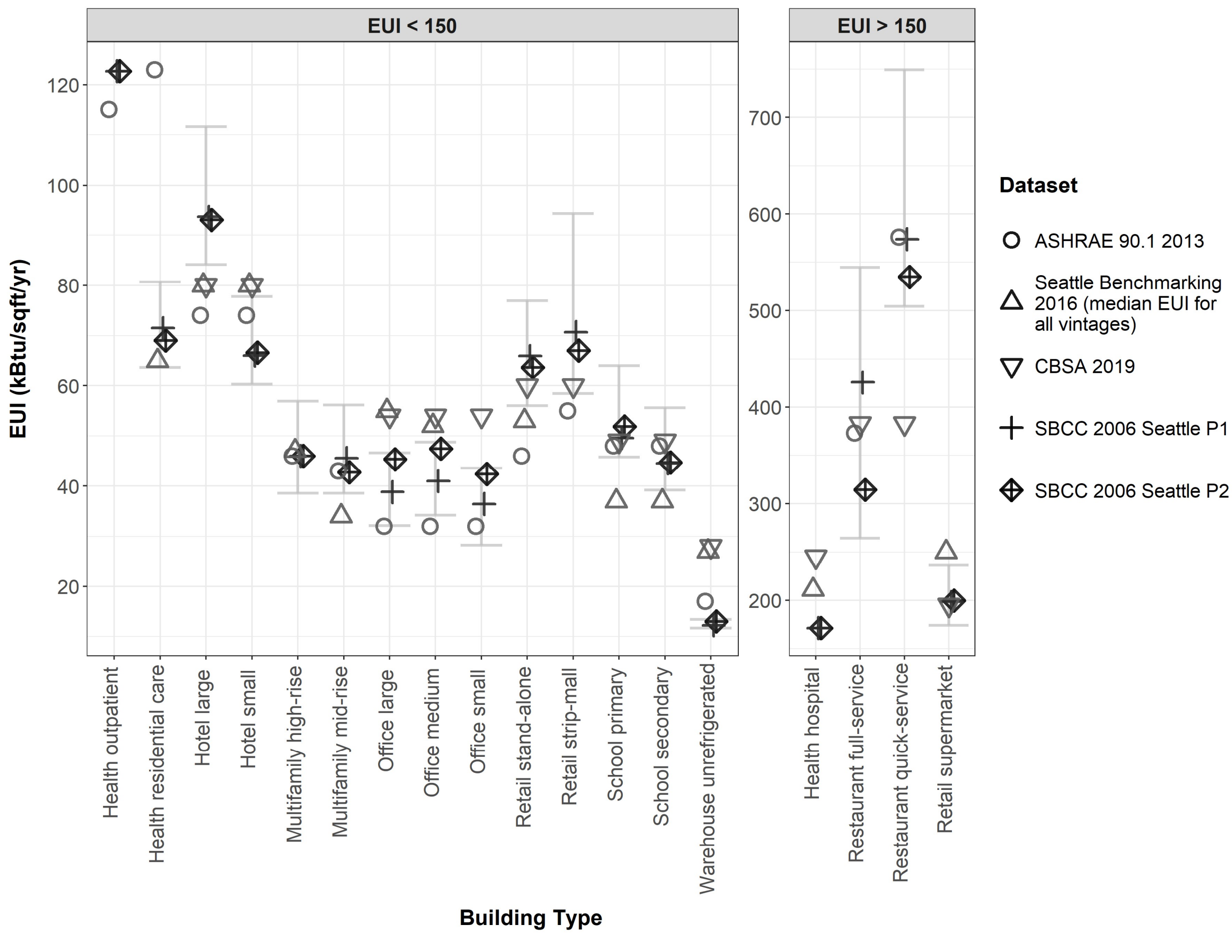


Figure 11. 2006 baseline model average EUI variation due to unregulated loads (4C Climate) with Comparison Datasets

The results in Figure 11 indicate that changes in modeling assumptions about unregulated loads could significantly change the mean EUI value of each building type. This would result in better alignment of modeled data with measured data, and a more accurate set of assumptions about code progress toward policy goals. (All building types other than Health Outpatient, Health Hospital, and Warehouse were included in the sensitivity analysis.) The ranges shown here suggest that the impact of unregulated loads on individual building types represents a significant unknown in determining overall building stock progress toward state mandates for a 60% performance improvement by 2030. To reduce the uncertainty associated with unregulated loads, subsequent field analysis of building stock should focus on more specifically identifying actual energy use patterns associated with unregulated loads, rather than focusing only on the impact of energy code measures. In particular, it would be important in the future to collect data about mean values for unregulated loads in the building stock, so that modeling inputs can reflect this value and therefore align more directly with measured data.

The results above also show that the modeled data on code performance is not completely out of line with measured results, when adjustments to unregulated loads and other non-code factors are considered. For many building types, the range of outcome for unregulated loads analyzed here encompasses the measured data for building performance from regional sources.

Updating the Baseline

The sensitivity analysis demonstrates that modified assumptions about unregulated loads and other key variables not controlled by code can explain a significant amount of variability between modeled and measured results. This provides critical insight into how to better track building stock performance improvements as a function of combined policy and market influences. Future analysis of building stock performance should include field data about unregulated loads to influence modeling assumptions and increase confidence in predicted performance results at the building type level.

For this analysis, performance patterns in certain building types suggest that these modifications should be implemented in the Phase One baseline analysis to improve confidence in the accuracy of the predicted 2006 baseline performance values. Using the research conducted in Phase Two on unregulated load characteristics, and research on control system performance and other characteristics, the project team has implemented some modifications to performance predictions for key building types. Most of these modifications result in only minor changes to EUI, but the analysis has significant implications for code priorities; in some cases the modifications result in more reasonable end use energy predictions that provide better context for evaluating the potential impact of subsequent code strategies to lead to continued building performance improvement.

In the context of specific building types, Table 15 shows how the results of the sensitivity analysis were applied to the 2006 baseline EUI values. The table also shows the comparative measured value for each building type, and the fraction of total floor area represented by the building type. This information helps to recognize the significance of any EUI variations in the context of the larger building stock.

Table 15. Comparison of Phase One and Phase Two EUI Values.

Building Type	2006 Phase 1 EUI	2006 Phase 2 EUI	CBSA 2019 (approx.)	Fraction of Total Floor Area
Office large	40	47	54	10.7
Office small	39	46		7.8
Office medium	43	50		7.4
Retail stand-alone	70	68	60	18.1
Retail strip-mall	76	72		2.6
Warehouse unrefrigerated	14	15	28	14.2
School primary	52	54	49	5.7
School secondary	47	47		2.4
Multifamily mid-rise	47	44	34*	6.2
Multifamily high-rise	48	48	47*	0.7
Hotel large	98	97	80	5.2
Hotel small	69	69		0.7
Health outpatient	125	125		5.6
Health residential care	74	71		4.8
Health hospital	174	174	245	3.4
Retail supermarket	202	204	195	2.4
Restaurant full-service	437	323	383	1.5
Restaurant quick-service	588	548		0.5
*Data from Seattle Benchmarking				

It is critical to note that although some of the individual EUI adjustments made based on the sensitivity analysis were significant, the overall weighted EUI value of the baseline changed less than 1% from the overall weighted value predicted in Phase One of this analysis. (See Figure 7 at the beginning of the Commercial Results section of this report.) The adjusted values for unregulated loads in the 2006 baseline basically balance each other out across the building sector in this analysis. This suggests that while there is room for significant improvement in understanding individual building characteristics and end use breakdown, no change has been suggested to the overall weighted analysis of the relative stringency of the 2018 WSEC relative to the 2006 baseline code.

CONCLUSION

This study focused on capturing all savings directly attributed to the Washington's energy code and other mandatory policies (state laws, mechanical codes), and on assessing strategies to better align predicted energy use with measured data collected in regional studies. The annual energy consumption and estimated savings between 2006 and 2018, represent savings from regulated energy loads (lighting, HVAC, and service water heating) since they are governed by the energy code.

The study is informed by several building stock assessments that were conducted around the time that the 2006 Washington State Energy Code came into effect. These provided a fairly robust set of references in which to source prototypical data, such as building type weighting by floor area, common heating fuel sources, and a reference to metered and bill utility data. However, for the 2018 analysis, comparable data about current building trends does not exist. In the absence of this data, this study elected to keep values for unregulated loads, fuel selection, and other building characteristics consistent between the 2006 and 2018 analysis to assess code impacts independently of other trends in building performance. This suggests that additional performance improvements adopted by the market might not be reflected in the 2018 analysis.

The residential energy code has a narrower focus when compared to commercial code since it is focused on only two building types – single family and low-rise multifamily. As such, from a code analysis standpoint, predicting end-use consumption is much more straightforward than in the commercial sector. There are only four predominant HVAC systems, associated control systems are simple, occupant behavior is more-or-less predictable, there is less interaction between system selection and energy consumption, and unregulated process loads are more consistent. All these traits mean that a well-developed residential code can be relied upon to bring energy cost savings across the sector.

The commercial sector, on the other hand, encompasses a wide range of building types, each with substantially different annual energy end-use characteristics.

A key assumption in this study (and a common assumption among similar studies) is that the energy code does not directly incentivize fuel switching. The code mandates the efficiency of equipment and guides the design of selected systems, but does it not directly affect designer or builder preferences on heating source (fossil-gas vs. electricity). Without building stock surveys and supporting data showing a noticeable deviation in standard building practice, fuel sources were kept constant across both 2006 and 2018 code years. It is expected that future modeling studies of code savings will need to account for evolving fuel choices as the focus of policy turns to carbon emissions as opposed to site energy consumption.

The initial goal of this analysis was to provide an evaluation of the baseline code upon which state building policy is based (2006) and to assess the degree to which current 2018 code improvements have followed the performance trajectory identified in the policy. This analysis was defined as a 'model-to-model' analysis of the impact of code improvements on building energy performance, independent of market and building stock changes occurring simultaneously to the code development period identified in the analysis. Although the analysis has helped to inform us about energy code progress over this time period, specific limitations and potential inaccuracies of this approach became apparent through the modeling process, particularly when the results were compared to measured building performance data. There were also some results that may have mischaracterized assumptions about building end use. The initial prototypes were defined to include plug and equipment loads taken from the regionally accepted RTF prototype assumptions. Because equipment loads represent internal gains in the buildings, in some cases the modeling predicted that these loads were significantly offsetting the need for heat in the modeled prototypes. Several of the prototype models suggested that certain building types in 2018 require very little heating, or even no heating at all, through the course of a year. This is often at odds with billing analyses of new buildings that show significant heating energy being used in our climate.

To address this issue, a second phase of analysis was undertaken to assess the degree to which unregulated loads, operating characteristics, and other building characteristics not regulated by code might be influencing the results. This sensitivity analysis allowed the project team to identify a range of outcome for performance predictions that could be driven by changes in assumptions about these non-code characteristics. These performance ranges were compared to measured data on building performance to better understand the alignment of predicted and actual building performance outcomes. To support this process, the project team identified various field data and analysis sources that suggested alternate values for unregulated load characteristics, other sensitivity analyses that identified relative impacts of various inputs, and field research on building operating characteristics. Unfortunately, few of these sources included a thorough exploration these issues through a systematic, statistically robust research design, and did not represent all building types in the study. The team was left to make judgements on the degree to which these factors should be incorporated into the final results for the 2006 baseline.

The potential implications of these assumptions on code and policy development are significant. In the case where unregulated loads are assumed to be high, the modeled results suggest that no significant additional savings are available from energy conservation measures targeting heating energy use reduction, and that the code should focus elsewhere. But Ecotope's experience with building performance suggests that very few buildings actually include such high levels of internal gains, and the internal gains that are present are not available for even distribution around the building to offset heating loads. De-emphasizing the role of building heating loads in future code requirements could miss significant opportunities for real energy use reductions. And if in the future successful strategies are developed to more effectively manage or limit equipment loads that lead to internal gains, the 'missing' heating loads will quickly reappear in these buildings.

The second phase of this analysis demonstrates that unregulated loads and non-code building characteristics are critical to accurate predictions of building performance outcomes, particularly with respect to understanding energy end use breakdowns and the code opportunities these represent. However this type of analysis is lacking from previous modeling analyses of code impacts and progress. As the State of Washington proceeds on energy code development and tracking building performance progress, it will be critical that specific information be collected in subsequent field work that supports more accurate modeling of these aspects of building performance.

REFERENCES

ASHRAE. *Advanced Energy Design Guide for Grocery Stores.*

BEE Software Collaborative: An Open Source, Rule-Based Architecture for Building Energy Efficiency. https://www.aceee.org/files/proceedings/2012/data/papers/0193-000379.pdf

Fernandex, Xie, Katipamula, Zhao, Wang, Corbin. (2017). Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction. https://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf

Fricke, Brian A. (2011) *Waste Heat Recapture from Supermarket Refrigeration Systems*. Oak Ridge National Laboratory.

Northeast Energy Efficiency Partnerships. (2011). *C&I Lighting Load Shape Project*. KEMA

Northwest Energy Efficiency Alliance. (2019). *2015 Washington State Energy Code: Residential Impact Assessment.* Ecotope, Inc

Northwest Energy Efficiency Alliance. (2020). *2019-2020 Washington Residential New Construction Code* Study. CLEAResult.

Northwest Energy Efficiency Alliance. (2008). *Baseline Characteristics of the 2002-2004 Nonresidential Sector: Idaho, Montana, Oregon, and Washington*. Ecotope, Inc.

Northwest Energy Efficiency Alliance. (2014). *Commercial Building Stock Assessment (CBSA).* Navigant Consulting.

Northwest Energy Efficiency Alliance. (2007). *Multifamily Residential New Construction Characteristics and Practice Study*. RLW Analytics.

Northwest Energy Efficiency Alliance. (2014). *Residential Building Stock Assessment: Metering Study.* Ecotope, Inc.

Northwest Energy Efficiency Alliance. (2007). *Single-Family Residential New Construction Characteristics and Practice Study*. RLW Analytics.

Roth, Kurt & Westphalen, Detlef & Feng, Michael & Llana, Patricia. (2005). Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential. https://www.researchgate.net/publication/242718245_Energy_Impact_of_Commercial_Building_Controls_and_Performance_Diagnostics_Market_Characterization_Energy_Impact_of_Building_Faults_and_Energy_Savings_Potential

APPENDIX A – DETAILED RESIDENTIAL BUILDING INPUTS

Table 16. Residential Building Prototypical Characteristics

Prototype	Descr	Bed/ Unit	Occ/ Unit	Total Units	Found Type	Cond Area, CFA (sf)	Vol (ft^3)	Ext Floor Area (sf)	Ext Wall Area (sf)	Roof Area (sf)	Glazing % CFA	Door Area (sf)	2006 Vent CFM	2018 Vent CFM	Supply Duct Loc	Return Duct Loc
1344c	sf home	3	2	1	Crawl	1344	10752	0	1184	1344	13%	40	75	45	Crawl	Attic
1344s	sf home	3	2	1	Slab	1344	10752	0	1184	1344	13%	40	75	45	Attic	Attic
2200c	sf home	4	2.8	1	Crawl	2200	18700	200	2210	1784	16.6%	40	100	65	Crawl	Attic
2200s	sf home	4	2.8	1	Slab	2200	18700	200	2210	1784	16.6%	40	100	65	Attic	Attic
2688b	sf home	4	3.5	1	Bsmt	2688	22848	0	1480	1344	14%	40	105	70	In	Attic
5000b	sf home	4	4	1	Bsmt	5000	40100	200	2788	1800	15%	40	125	90	In	Attic
1500c	townhome	3	1.7	1	Crawl	1500	14250	0	1259	500	13%	40	75	45	Crawl	Attic
1500s	townhome	3	1.7	1	Slab	1500	14250	0	1259	500	13%	40	75	45	Attic	Attic
1000c	Dbl loaded corridor	2	1.7	24	Crawl	26400	237600	0	10152	8800	15%	84	1680	960	In	In
0952s	garden style	2	1.7	8	Slab	7616	64736	0	6528	3808	15%	160	440	280	In	In
0952c	garden style	2	1.7	8	Crawl	7616	64736	0	6528	3808	15%	160	440	280	Crawl	Attic

Table 17. Residential Building Code Minimum Default Inputs by Code Year

Code Year	IECC Climate Zone	Roof Ins (R-val)	Wall Ins (R-val)	Wall Framing Type	Floor Ins (R-val)	Bsmt Wall Ins (R-val)	Slan Ins (R-val, ft)	Glazing (U-val, SHGC)	Door (U-val)	Duct Ins (R-val)	Duct Leak (CFM/ 100sf)	Env Infil (ACH50)	Exhaust Fan Eff (CFM/W)
WA06	4C	38	21	std	30	19	10, 2ft	0.35, 0.32	0.2	8	0.12	7	0.86
WA06	5B	38	19 +5ci	std	30	19	10, 2ft	0.32, 0.31	0.2	8	0.12	7	0.86
WA18	4C	49	21	int	30	21	10, 2ft	0.3, 0.3	0.3	8	0.04	5	1.4
WA18	5B	49	21	int	30	21	10, 2ft	0.3, 0.3	0.3	8	0.04	5	1.4

APPENDIX B – DETAILED RESIDENTIAL MODELING RESULTS

Run Label	Dwelling Size (Section R406)	Heating Fuel	Heat, kWh	Heat, Therm	Cool, kWh	Fan, kWh	Lights, kWh	DHW, kWh (Therm)	Appliances and Plugs, kWh	Total kWh	Total Therms	Total kWh/Unit Equiv
WA06_0	Single Family Small	gas	167	259	140	255	1397	(140)	5533	7491	399	19175
WA06_0	Single Family Small	elec	3339		336	255	1397	2499	5533	13359		13359
WA06_0	Single Family Medium	gas	357	512	202	342	2358	(187)	5533	8792	698	29255
WA06_0	Single Family Medium	elec	6280		470	342	2358	3337	5533	18320		18320
WA06_0	Single Family Large	gas	578	724	278	424	5197	(246)	5533	12010	970	40421
WA06_0	Single Family Large	elec	9151		626	424	5197	4400	5533	25330		25330
WA06_0	Multifamily (R-2)	elec	2272			210	1015	1703	4121	9320		9320
WA18_1	Single Family Small	gas	132	176	94	138	277	(119)	5533	6174	295	14812
WA18_1	Single Family Small	elec	1976		231	247	277	2272	5533	10535		10535
WA18_1	Single Family Medium	gas	199	244	125	201	468	(121)	4693	5686	365	16382
WA18_1	Single Family Medium	elec	3633		319	251	468	1153	4693	10517		10517
WA18_1	Single Family Large	gas	276	297	182	563	1030	(160)	4693	6745	457	20137
WA18_1	Single Family Large	elec	5398		442	276	1030	1520	4893	13558		13558
WA18_1	Multifamily (R-2)	elec	1191			272	205	588	4121	6377		6377

APPENDIX C – COMMERCIAL HVAC SYSTEM TYPES

Table 18. Modeled 2006 Commercial HVAC System by Prototype

	WSEC 2006 HVAC Systems	
Prototype Model Weights (if applicable)	**HVAC System - A**	**HVAC System - B**
Small Office System A = 75% System B = 25%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Medium Office	Central VAV† Heating: elec central + elec VAV boxes Cooling: DX + economizer	
Large Office	Central VAV† Heating: elec central + elec VAV boxes Cooling: DX + economizer	
Stand-alone Retail System A = 85% System B = 15%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Strip Mall System A = 85% System B = 15%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Supermarket	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	
Primary School	VAV serving corridors and classrooms† Heating: HW boiler central Cooling: CHW with cooling tower, economizers (30% min damper) Single-zone RTUs for all other spaces† Heating: Gas furnace Cooling: DX, economizers	
Secondary School	VAV serving corridors and classrooms† Heating: HW boiler central Cooling: CHW with cooling tower, economizers (30% min damper) Single-zone RTUs for all other spaces† Heating: Gas furnace Cooling: DX, economizers	
Small Hotel	Guestrooms: PTHPs w/ electric backup heat† Common areas: Split AC/furnace Vent = bathfan @ const volume	
Large Hotel	Guestrooms: FPFCs with DOAS† Common areas: Single-duct VAV systems, HW Reheat Heating: Gas Boiler Cooling: Chiller and Cooling Tower, economizer	

	WSEC 2006 HVAC Systems (Continued)	
Prototype Model	HVAC System - A	HVAC System - B
Hospital	Both constant air volume (CAV) and VAV systems† All system use ChW/HW with hydronic reheat.	
Warehouse (non-refrigerated)	Office/fine storage: Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer Bulk storage: Gas unit heater (CV fan) †	
Quick Service Restaurant	Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer	
Full-Service Restaurant	Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer	
Outpatient Healthcare	Central VAV - Hydronic heating and cooling. Heating: Hydronic reheat	
Mid-rise Apartment	Zone Exhaust PTAC Heating: Elec Resist Cooling: DX	
High-rise Apartment	Zone Exhaust WSHPs on condensor loop (Cali HP loop) Heat: Boiler, zonal HPs Cooling: Cooling tower, zonal HPs	
Residential Care	Zone Exhaust† PTAC Heat: Elec Resist Cooling: DX Common area: VAV w/ elec resistance reheat	
† Consistent with RTF default HVAC assumptions		

Table 19. Modeled 2018 Commercial HVAC System by Prototype

	WSEC 2018 HVAC Systems	
Prototype Model Weights (if applicable)	**HVAC System - A**	**HVAC System - B**
Small Office System A = 75% System B = 25%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Medium Office	DOAS with ERV - elec tempering VRF FCUs Heating: VRF Cooling: VRF	
Large Office	DOAS with ERV - elec tempering VRF FCUs Heating: VRF Cooling: VRF	
Stand-alone Retail System A = 85% System B = 15%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Strip Mall System A = 85% System B = 15%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Supermarket	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Primary School	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Secondary School	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Small Hotel	Guestrooms: PTHPs w/ electric backup heat Common areas: Split AC/furnace Vent = bathfan @ const volume	
Large Hotel	Guestrooms: FPFCs with DOAS Common areas: Single-duct VAV systems, HW Reheat Heating: Gas Boiler Cooling: Chiller and Cooling Tower, economizer	

	WSEC 2018 HVAC Systems (Continued)	
Prototype Model	**HVAC System - A**	**HVAC System - B**
Hospital	Both constant air volume (CAV) and VAV systems depending on the zone. All systems use ChW/HW with hydronic reheat. HRC post processing calculation per C403.9.2.4	
Warehouse (non-refrigerated)	Office/fine material storage: Packaged RTU Single zone Heat: Gas Cooling: DX + economizer Bulk storage: Gas unit heater (CV fan)	
Quick Service Restaurant	Packaged RTU Single zone Heat: Gas Cooling: DX + economizer	
Full-Service Restaurant	Packaged RTU Single zone Heat: Gas Cooling: DX + economizer	
Outpatient Healthcare	Central VAV - Hydronic heating and cooling. Heating: Hydronic reheat	
Mid-rise Apartment	Balanced Zone Ventilation, ERV 60% sensible PTAC Heating: Elec Resist Cooling: DX	
High-rise Apartment	Balanced Zonal Ventilation, ERV 60% sensible WSHPs on condensor loop (Cali HP loop) Heat: Boiler, zonal HPs Cooling: Cooling tower, zonal HPs	
Residential Care	Zone Exhaust PTAC Heat: Elec Resist Cooling: DX Common area: VAV w/ elec resistance reheat	

APPENDIX D – COMMERCIAL BUILDING TYPE DESCRIPTIONS

Table 20. Commercial Building Prototype Descriptions Compared to CBSA Building Types

Commercial Prototypes	CBSA Detailed Building Type Included	Other Criteria
Small Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	Less than 20,000 square feet
Medium Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	20,001 - 100,000 square feet
Large Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	Greater than 100,000 square feet
Stand-alone Retail	auto parts; auto/boat dealer/ show room; beauty / barber; car wash; clothing; department store; dry cleaner; electronics/appliances; florist, nursery; hardware; home improvement; laundromat (self-service); pharmacy; post office; rental center; repair shop; studio/gallery; vehicle repair; warehouse club; other specialty merchandise	Single stand-alone building
Strip Mall	auto parts; auto/boat dealer/ show room; beauty / barber; car wash; clothing; department store; dry cleaner; electronics/appliances; florist, nursery; hardware; home improvement; laundromat (self-service); pharmacy; post office; rental center; repair shop; studio/gallery; vehicle repair; warehouse club; other specialty merchandise	Part of larger mixed-use building
Supermarket	grocery	
Primary School	elementary school; middle school; pre-school; other k-12 school	
Secondary School	high school	
Small Hotel	motel; bed & breakfast; boarding/rooming house, apt hotel	
Large Hotel	hotel; hotel - resort	
Hospital	hospital	
Warehouse (non-refrigerated)	ministorage; warehouse, distribution; warehouse, storage; other warehouse	

Commercial Prototypes	CBSA Detailed Building Type Included	Other Criteria
Quick Service Restaurant	cafeteria; catering service; coffee, doughnut, or bagel shop; fast food restaurant; ice cream or frozen yogurt shop; take-out restaurant; truck stop	
Full-Service Restaurant	bar, pub, lounge; sit down restaurant; other restaurant	
Outpatient Healthcare	dental office; medical clinic / outpatient medical; medical office; medical urgent care clinic; outpatient rehab; veterinarian office/clinic	
Mid-rise Apartment	Not included in CBSA. Should represent all high rise (up to 4 stories) apartment buildings.	Census Data used to estimate number of apartments and square footage. Seattle Benchmarking Data used to estimate high rise to mid-rise split in urban area.
High-rise Apartment	Not included in CBSA. Should represent all low rise (greater than 4 story) apartment buildings.	Census Data used to estimate number of apartments and square footage. Seattle Benchmarking Data used to estimate high rise to mid-rise split in urban area.
Residential Care	assisted living; in-patient rehab; nursing home; retirement home; other residential care	

APPENDIX E – COMMERCIAL BUILDING MODELING INPUTS

Commercial building modeling inputs are summarized in a corresponding document.

APPENDIX F – MARKET RESEARCH RESULTS

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
ACEEE	2008	Richman, E. et al. (PNNL+)	Building Characteristics	Most commercial types	National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007
Readership	2018?	GE current (lighting products company)	Building Characteristics	Retail - grocery	How is the Grocery Store Footprint Changing?
NEEA	2004	Ecotope	CBSA	Most commercial types	Baseline Characteristics of the 2002-2004 Nonresidential Sector: Idaho, Montana, Oregon and Washington
NEEA	2008	Ecotope	CBSA	Most commercial types	Baseline Energy Use Index of the 2002-2004 Nonresidential Sector: Idaho, Montana, Oregon and Washington
NEEA	2009	Cadmus + Ecotope	CBSA	Most commercial types	Northwest Building Stock Assessment
NEEA	2014	Navigant	CBSA	Most commercial types	2014 Commercial Building Stock Assessment: Final Report
NEEA	2019	Cadmus	CBSA	Most commercial types	Commercial Building Stock Assessment 4 (2019) Final Report
Proceedings of the IEEE	2011	Baliga, et al.	Cloud Computing	Many commercial types	Green Cloud Computing: Balancing Energy in Processing, Storage, and Transport
NREL	2011	Sheppy, M. et al. (NREL)	Cloud Computing	Office	Reducing Data Center Loads for a Largescale, Low-energy Office Building: NREL's Research Support Facility
IEEE Cloud Computing	2015	Mastelic, T. and Brandic, I.	Cloud Computing	General commercial	Recent Trends in Energy-Efficient Cloud Computing
Forbes	2018	Columbus, L.	Cloud Computing	Many commercial types	State Of Enterprise Cloud Computing, 2018
Energy Innovation	2020	Masanet, E. and Lei, N. (NREL +)	Cloud Computing	General commercial	How Much Energy Do Data Centers Really Use?
NBI	2015	Frankel, M. and Edelson, J. (NBI)	Code Road Map	General commercial	Washington State Energy Code Roadmap
DOE	2015	PNNL	Code Road Map	General commercial	Roadmap for the Future of Commercial Energy Codes
NEEA	2008	NEEA	Commercial Code	General commercial	Non-Residential Energy Savings From Northwest Energy Code Changes 2005-2008

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
DOE	2005	TIAX	Commissioning	General commercial	Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential
NEEA	2016	Cadmus	Commissioning	General commercial	Commissioning LongTerm Monitoring and Tracking—2015 Square-Footage Update (2016 Study)
PNNL	2017	PNNL	Commissioning	Many commercial types	Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction
Slipstream	2018	Slipstream	Commissioning	General commercial	Persistence of Savings from Retro-Commissioning Measures
PNNL	2019	PNNL	Commissioning	Many commercial types	Basic HVAC Controls and Energy Codes ?
CEUS	2006	Itron	End Use	Most commercial types	California Commercil End-use Survey
DOE	2010	PNNL	End Use	Hotel	Energy End-Use Patterns in Full-Service Hotels: A Case Study
DOE	2014; Data from 2012	Sheppy, M. et al. (NREL)	End Use & Plug loads	Hospitals, Healthcare office	Healthcare Energy End-Use Monitoring
Seattle Office of Sustainability & Environment	2013	Seattle Office of Sustainability & Environment	Energy Benchmarking	General commercial	Building Energy Benchmarking Analysis Report 2013 Data
City of Portland	2018	Portland Bureau of Planning and Sustainability	Energy Benchmarking	Many commercial types	2018 Building Energy Performance Reporting Results
DOE		Various	Energy Benchmarking	Many commercial types	Policy, Permit, Perform: Using City Benchmarking Data and Building Construction Permit History to Identify Energy Performance Improvements
Legislature	2015	Energy Codes Council	Energy Code	Residential, General commercial	Washington state Energy Code Progress toward 2030
DOE	2016	Bartlett, R., et al. (PNNL)	Energy Code	Most commercial types	Commercial Building Energy Code Compliance Literature Review
U.S. Energy information Administration	2007	CBECS	Energy Use	Hospital - large	Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
ASHRAE	2016	Glazer	Energy Use	Most commercial types	Development of Maximum Technically Achievable Energy Targets for Commercial Buildings.
Energy and Buildings	2019	Ye, Y. et al.	Energy Use	General commercial	A Comprehensive Review of Energy-Related Data for U.S. Commercial Buildings
NEEA	2007	LBNL	Envelope - Windows	Office	Analysis of window energy savings in commercial buildings in the Pacific Northwest
Readership	2010	BuildingGreen	Envelope - Windows	Many commercial types	It's Time to Rethink the All-Glass Building
DOE	2015	PNNL	Envelope - Windows +	multi-family/office, mixed use	Preserving Envelope Efficiency in Performance Based Code Compliance
DOE	2018	Winiarski, D. et al. (PNNL)	Envelope + HVAC	Most commercial types	Analysis for Building Envelopes and Mechanical Systems Using 2012 CBECS Data
Slipstream	2015	Slipstream	Lighting	General commercial	Adjusting lighting levels in commercial buildings
EIA	2017	EIA	Lighting Controls	General commercial - large	Large commerial buildings more likely to use lighting control strategies
City of Seattle	2015	ARUP	Mechanical - HVAC	Many commercial types	Seattle High-Efficiency Space Heating Recommendations for Market Transition
BPA	2015	Cadeo+	Mechanical - HVAC	Residential	Commercial HVAC Market Characterization - 2015 Findings
Whole Building Design Guide	2016	Graham, C. (Viridian Energy & Environmental, Inc.)	Mechanical - HVAC	General commercial	High-Performance HVAC
CEE	2016	CEE	Mechanical - HVAC	Many commercial types	High Efficiency Commercial Air-conditioning and Heat Pumps Initiative
BPA	2018	Cadeo+	Mechanical - HVAC	General commercial	HVAC Technoflogy Guide
Readership	2020	Statista	Mechanical - SHW	General commercial	Commercial gas and electric storage water heater shipments in the U.S. from 2001 to 2019
DOE	2011	PNNL	MELs	Hotel	Assessing and Reducing Miscellaneous Electric Loads (MELs) in Lodging

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
ACEEE	2012	Lanzisera, S., et al. (PNNL+)	MELs	Office	Methods for detailed energy data collection of miscellaneous and electronic loads in a commercial office building
EIA	2013	Navigant Consulting & SAIC	MELs	General commercial	Analysis and Representation of Miscellaneous Electric Loads in NEMS
ACEEEDC	2013	Kwatra, et al.	MELs	Residential, General commercial	Micellaneous Energy Loads in Buildings
DOE	2005?	Fanara, et al. (EPA+)	MELs	Residential, offices, schools	How Small Devices are Having a Big Impact on U.S. Utility Bills
ASHRAE	Various	ASHRAE	Model Comparison	Most commercial types	ASHRAE 90.1 - various years - Energy Standard for Building Except Low-Rise Residential Buildings
EIA	2016; Data from 2012	EIA	Model Comparison	Most commercial types	Electricity consumption totals and conditional intensities by building activity subcategories, 2012
ASHRAE	2013; Data from 2009-2011	Duarte, C., et al. (University of Idaho, Idaho National Laboratory)	Occupancy	Office	Revealing Occupancy patterns in an office building through the use of occupancy sensor data
LBNL	2004	Roberson, J. et al. (LBNL)	Plug Loads	Many commercial types	After-hours Power Status of Office Equipment and Inventory of Miscellaneous Plug-load Equipment
Science Direct	2011	Srinivasan, R., et al.	Plug Loads	K-12 schools	Plug-load densities for energy analysis: K-12 schools
CEC	2011	ECOS	Plug Loads	Office	Office Plug Load Field Monitoring Report - PIER Final Project Report
ACEEE	2012	Acker, B. et al. (University of Idaho)	Plug Loads	Office	Office Space Plug Load Profiles and Energy Saving Interventions
NREL	2012	Locato, C, et al. (NREL)	Plug Loads	Office	Selecting a Control Strategy for Plug and Process Loads
GSA	2013	Institute for the Built Environment	Plug Loads	Office	Plug Load Research Review Summary
NREL	2013	NREL	Plug Loads	Office	Assessing and Reducing Plug and Process Loads in Office Buildings

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
Science Direct	2014	Fuentes, G. And Schiavon, S. (Center for the Built Environment)	Plug Loads	Office	Plug load energy analysis: The role of plug loads in LEED certificationand energy modeling
NREL	2014	Sheppy, M, et al. (NREL)	Plug Loads	Office, Higher Education	An Analysis of Plug Load Capacities and Power Requirements in Commercial Buildings
U.S.Dept. Energy	2014	Sheppy, M. et al. (NREL+)	Plug Loads	Office, Higher Education	Plug and Process Loads Capacity and Power Requirements Analysis
EIA	2017	EIA	Plug Loads	Education	Computer and technology use in education buildings continues to increase
Cadmus	2017	Cadmus	Plug Loads	Multifamily, Office, K-12 Schools	Variance and Optimization in Nonresidential Building Simulation Receptacle Loads
DOE-BetterBuildings	2018?	NREL	Plug Loads	Office	Office Building Plug Load Disaggregation
DOE-BetterBuildings	Various	DOE	Plug Loads	Many commercial types	Better Buildings Plugs and Process Loads - website resources
Readership	2000	US teleworkers	Remote Workforce	Office, other?	Telework In the US Telework America Survey 2000
CEA	2007	TIAX	Remote Workforce	Office	The Energy and Greenhouse Gas Emissions Impact of Telecommuting and e-Commerce
Sun Microsystems	2008	Sun Microsystems	Remote Workforce	Office	Sun Microsystems Study Finds Open Work Program Saves Employees Time and Money, Decreases Carbon Output
US Census	2010	US Census	Remote Workforce	Office, other?	Home-Based Workers in the US: 2010
American Psychological Association	2019	Greenbaum, Z.	Remote Workforce	Office, other?	The future of remote work
Readership	2019	Volusion	Remote Workforce	Office, other?	Cities With the Most Remote Workers
Readership	2020	Gallup	Remote Workforce	Office	Is Working Remotely Effective? Gallup Research Says Yes
Readership	2020	Global Workplace Analytics	Remote Workforce	Office, other?	Latest Work-At-Home/Telecommuting/Mobile Work/Remote Work Statistics
Readership	2020	KOMO	Remote Workforce	Office, other?	New study finds that nearly 8% of Seattleites work remotely

Prepared_for	Year	Prepared_by	Topic	Building Type	Title
Readership		Flexjobs	Remote Workforce	Office, other?	Remote Work Statistics: Shifting Norms and Expectations
DOE	2015	DOE	Various	Many commercial types	Quadrennial Technology Review - An Assessment of Energy Technologies and Reseach Opportunities
EIA	2017	EIA	Various	General commercial - large	Commercial Buildings Energy Consumption Survey (CBECS)
NEEA	2019	Ecotope	Various	Select commercial	2019 Oregon New Commercial Construction Code Evaluation Study
DOE	2020	Ecotope	Various	Multifamily	Residential Building Energy Efficiency Field Studies: Low-Rise Multifamily
ASHE	?	ASHE	Various	Hospitals	Sustainability Roadmap for Hospitals
Slipstream	2015	Slipstream	Ventilation	General commercial	Energy savings from implementing and commissioning demand control ventilation